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NASA

FINAL REPORT

HIGH-PRESSURE HOT-GAS SELF-ACTING FLOATING RING SHAFT SEAL FOR LIQUID ROCKET TURBOPUMPS

by

R. E. Burcham and W. A. Diamond

Rockwell International
Rocketdyne Division

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

September 1980

NASA-Lewis Research Center

Contract NAS3-19425

R. C. Hendricks, Project Manager

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16. Abstract
Design analysis, detail design, fabrication, and experimental evaluation was performed on two self-acting floating ring shaft seals for a rocket engine turbopump high-pressure 24132500 n/m^2 (3500 psig) hot-gas 533 K (500 F) high-speed 3142 rad/sec (30000 rpm) turbine.

The initial design used Rayleigh step hydrodynamic lift pads to assist in centering the seal ring with minimum rubbing contact. The final design used a convergent tapered bore to provide hydrostatic centering force.

The Rayleigh step design was tested for 107 starts and 4.52 hours total. The leakage was satisfactory; however, the design was not acceptable due to excessive wear caused by inadequate centering force and failure of the sealing dam caused by erosion damage.

The tapered bore design was tested for 370 starts and 15.93 hours total. Satisfactory performance for the required life of 7.5 hours per seal was successfully demonstrated.

17. Key Words (Suggested by Author(s))
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FOREWORD

This program was sponsored by the National Aeronautics and Space Administration, Lewis Research Center, Fluid Systems Components Division, under Contract NAS3-19425. The period of performance was March 1975 to September 1980.

The NASA Project Manager was Mr. W. F. Hady from start to March 1977, Mr. L. P. Ludwig from March 1977 to January 1980 and Mr. R. C. Hendricks from January 1980 to completion. The Contracting Officer was Mr. Leonard Schopen. Design support and technical consultation was provided by Dr. D. P. Fleming and Mr. G. P. Allen.

The Rocketdyne Program Manager was Mr. H. G. Diem. The Project Engineer was Mr. R. E. Burcham. Technical assistance was provided by Mr. W. A. Diamond and Mr. M. A. Hartman.

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GLOSSARY

Symbols n and N are used for the unit newton.

Symbols m and M are used for the unit meter.

Symbols cm and CM are used for the unit centimeter.

The SI units are converted from measurements made in U.S. Customary units. The accuracy of the converted units is no greater than the measured values.

SUMMARY

A design analysis and experimental evaluation of two different self-acting floating-ring shaft seals was performed. The objective of the program was to develop technology for rocket engine turbopump high-pressure 24132500 n/m^2 (3500 psig), hot-gas 533K (500 F), high-speed 3142 rad/sec (30000 rpm) turbine seals. The initial design utilized Rayleigh step hydrodynamic lift pads on the inside diameter to assist in centering the seal ring with minimum rubbing contact. The final design used a convergent tapered bore to provide hydrostatic centering force.

Analysis of the Rayleigh step lift pads indicated that the maximum lift force is 23.6 n (5.3 pounds) for the primary seal and 16.5 n (3.7 pounds) for the secondary seal. The radial friction force is 689 n (154 pounds) for the primary seal and 56.5 n (12.7 pounds) for the secondary seal; therefore, rubbing contact is required to center the seal rings.

The Rayleigh step design was tested for 107 starts and 4.52 hours total. The testing consisted of the following:

1. <u>Preliminary Checkout</u>: Two seals tested for 12 starts and 29.25 minutes with ambient temperature gaseous nitrogen at 1723750 to 22064000 n/m^2 (250 to 3200 psig) and 3351 rad/sec (32000 rpm).
2. <u>Hot GN_2 Testing</u>: Two seals tested for 8 starts and 20 minutes with 533 K (500 F) maximum GN_2 at 3447500 to 24.32500 n/m^2 (500 to 3500 psig) and 3351 rad/sec (32000 rpm).
3. <u>Hot GN_2 Acceleration Testing</u>: Two seals tested for 87 starts and 3.7 hours with 533 K (500 F) maximum GN_2 at 24132500 n/m^2 (3500 psig) with acceleration to 3351 rad/sec (32000 rpm) within 10 seconds.

The Rayleigh step design was unsatisfactory due to excessive wear caused by inadequate centering force and failure of the sealing dam caused by erosion damage.

Analysis of the tapered bore seal indicated that the hydrostatic centering force exceeds the radial friction force by a significant margin. The maximum hydrostatic centering force is 1659 n (373 pounds) for the primary and 60.0 n (13.5 pounds) for the secondary. The radial friction force is 827 n (186 pounds) for the primary and 31.1 n (7.0 pounds) for the secondary. The seal rings should be centered by the hydrostatic force during steady-state operation without rubbing contact.

The tapered bore design was tested for 370 starts and 15.93 hours total. The following tests were performed:

1. <u>Hot GN_2 Testing</u>: Two seals tested for 8 starts and 21.1 minutes with 533 K (500 F) maximum GN_2 at 3447500 to 24132500 n/m^2 (500 to 3500 psig) and 3037 rad/sec (29000 rpm).

2. Hot GN_2 Acceleration Testing: Two seals tested for 43 starts and 1.8 hours; two seals tested for 139 starts and 5.8 hours; and two seals tested for 180 starts and 8.0 hours for a total of six seals, 362 starts and 15.58 hours with 533 K (500 F) GN_2 at 24132500 n/m^2 (3500 psig) with acceleration to 3037 rad/sec (29000 rpm) within 10 seconds.

The tapered bore seal demonstrated satisfactory performance for the required life of 7.5 hours. The leakage rate varied from 0.59 to 0.77 kg/sec (1.3 to 1.7 lb/sec) on the pump end seal from 0.59 to 0.95 kg/sec (1.3 to 2.1 lb/sec) on the turbine end seal. The data indicate negligible wear on the primary seal rings and gradual but acceptable wearing of the secondary seal rings. The performance is considered satisfactory if the seal is functional and the leakage is acceptable at completion of testing.

INTRODUCTION

Rotating shaft seals used for rocket engine turbopump high-pressure hot-gas turbines have required significant advances in sealing technology. The labyrinth-clearance-type seals used for most high-pressure turbines generally are not satisfactory on a rocket engine turbopump turbine due to shaft stability and high leakage. Dynamic stability of the rotating shaft generally requires the damping provided by a bushing type circumferential shaft seal. The leakage must be minimized to provide fail-safe separation of the fuel-rich hot gas and the liquid oxidizer propellant on the same shaft.

Floating-ring controlled-gap-type shaft seals have been used to minimize operating clearance between the stationary housing and rotating shaft. The floating ring moves freely in the radial direction to center on the shaft location, thereby eliminating the concentricity tolerances of a fixed labyrinth. The floating ring will adjust to shaft radial displacements during critical speed or dynamic transients to maintain minimum clearance.

The conventional floating-ring shaft seals utilize a solid cylindrical ring with a smooth, straight bore. The hydrodynamic and hydrostatic forces developed by a smooth, straight-bore floating ring are generally not sufficient to center the ring without additional radial force from rubbing contact when the sealed fluid is a gas. Excessive rubbing causes wear and increased leakage.

Recent developments have indicated that self-acting hydrodynamic and hydrostatic concepts are capable of providing additional lift force to assist in centering the floating ring with minimum rubbing contact. Rayleigh step lift pads develop a hydrodynamic lift force by viscous pumping from rotation. Hydrostatic forces developed by pressure differential across the seal ring are considerably increased with a convergent taper on the bore.

The objective of the program was to develop technology for high-pressure 24132500 n/m^2 (3500 psig), hot-gas 533 K (500 F), high-speed 3142 rad/sec (30000 rpm) self-acting floating-ring shaft seals. A design analysis and experimental evaluation was performed on the Rayleigh step and tapered bore concepts. The scope of the program was revised to include the tapered bore seal after the Rayleigh step concept proved to be unsatisfactory. The program was successfully completed with the tapered bore seal.

The tapered bore seal technology developed on this program has been successfully applied to the space shuttle's main rocket engine turbopumps to assist in solution of significant turbine seal problems.

SEAL DESIGN

A design analysis and detail design was performed on two different turbine hot-gas seal configurations. The initial design was a floating-ring controlled-gap shaft seal with self-acting Rayleigh step hydrodynamic lift pads on the inside diameter to center the rings without rubbing contact. The final design was a floating-ring controlled-gap shaft seal with a convergent tapered bore for hydrostatic centering.

The Rayleigh step seals were designed to the following specifications:

Fluid: Gaseous nitrogen

Temperature: 294 K (70 F) and 533 K (500 F)

Pressure:

Primary: 27579028 n/m^2 (4000 psia)

Secondary: 586054 n/m^2 (85 psia)

Drain: 137900 n/m^2 (20 psia)

Speed: 3351 rad/sec (32000 rpm)

Shaft Rotating Eccentricity:

Transient: .000406 m (.016 in.) total

Steady: .000025 m (.001 in.) total

Shaft Diameter: .0644 m (2.5373 in.)

Number of Starts: 150

Operating Life: 7.5 hours

The tapered bore seals were designed to the same specifications, except as follows:

Temperature: 811 K (1000 F)

Pressure:

Primary: 26201000 n/m^2 (3800 psia)

Secondary: 1034250 n/m^2 (150 psia)

The seal assembly (Fig. 1) consists of a primary seal ring and a secondary seal ring. The cavity between the seal rings and the cavity on the low pressure side is drained to atmosphere. The seal rings are loaded against the housing side

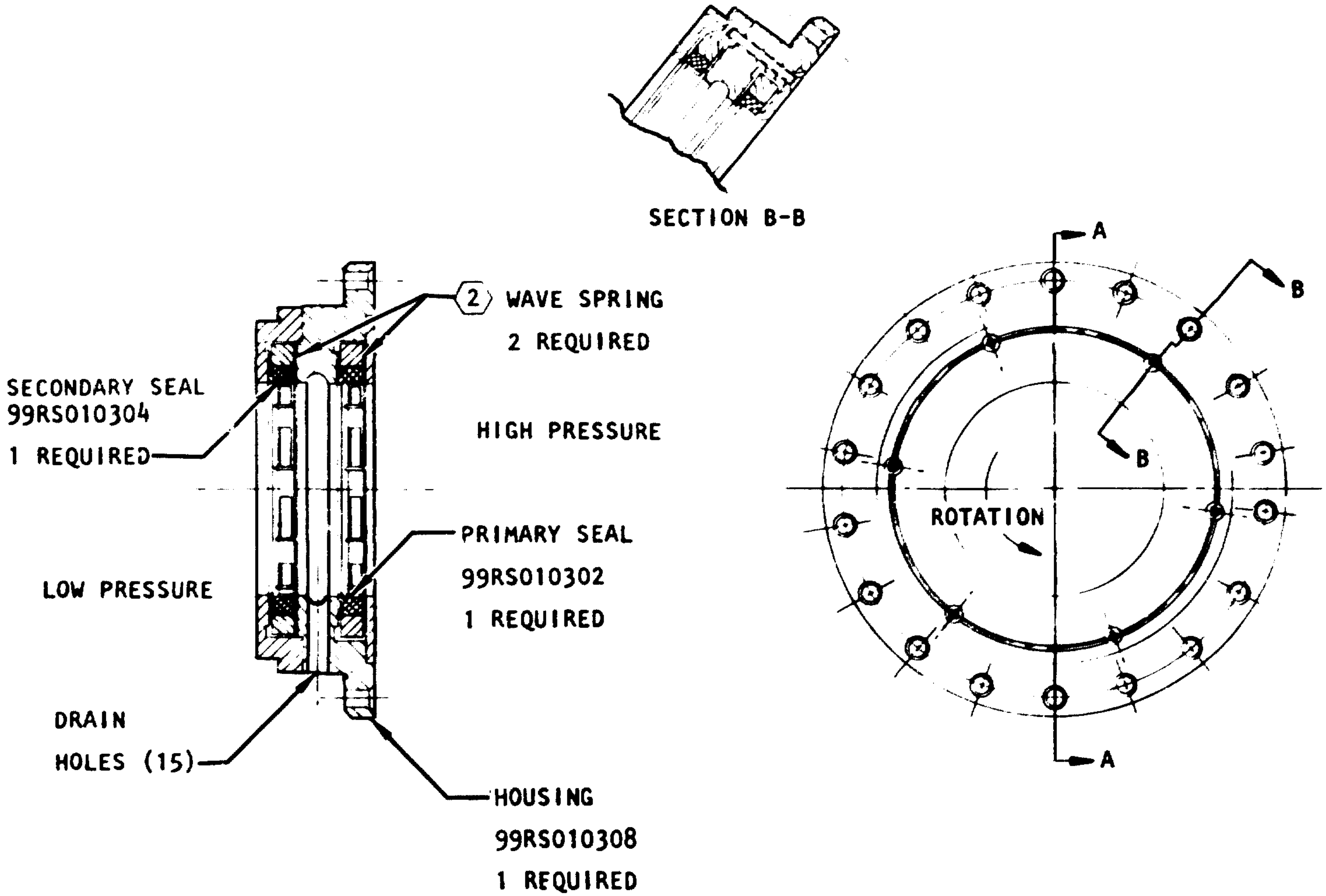


Figure 1. Rayleigh Step Pad Turbine Seal Assembly

surface with a wave spring. The wave spring load is 22.24 to 31.13 n (5 to 7 lbs). The rings are free to float in the radial direction, but are restrained from rotation with anti-rotation tangs. The side surface of the seal ring is relieved for pressure balance. The unbalanced axial load is supported by the housing. The carbon nose axial surface is lapped flat for sealing. The seal ring inside diameter is grooved around the Rayleigh pads to vent the pressure up to the seal dam for pressure balance. The unbalanced radial pressure load is supported by the seal ring in compressive hoop stress. Two designs were completed to allow installation of two seals back to back in the tester. The designs are the same except for reverse rotation.

A seal concept trade study to evaluate metal-banded carbon rings, metal-banded Am Cer Met 701-65 rings, and solid carbon rings was performed. A comparison of the stress and deflection calculated by finite element analysis, for the different seals is shown in Table 1. The results indicate that the Inconel X 750 metal-banded carbon G84 insert design is satisfactory for the 533 K (500 F) operating temperature. The metal-banded carbon ring operating deflection can be matched to the tester shaft operating deflection by varying the metal band to carbon ring interface radius. The solid carbon design is unsatisfactory due to low thermal expansion and excessive pressure deflection.

RAYLEIGH STEP LIFT PAD

Rayleigh step lift pads provide hydrodynamic lift for noncontact operation except during the start and stop transients. A fluid film is developed in the recessed pads by viscous pumping to assist in support of the seal ring in order to minimize rubbing contact. The fluid film thickness is controlled by the hydrodynamic lifting force in the pad. The lift force decreases for a larger gap and increases for a smaller gap. The floating seal ring seeks an equilibrium position where the gap is constant around the shaft. When the shaft moves off center, the unbalanced radial load tends to recenter the seal ring.

The Rayleigh step lift pad analysis was performed by NASA using a computer program entitled NASA Revised Self-Acting Lift Pad Design Program for Gas Film Seals (Ref. 1). The detail design of the Rayleigh pad seal rings is shown in Fig. 2 and 3 .

The lift pad geometry was optimized for gaseous nitrogen at 533 K (500 F). The calculated maximum lift force at .00000127 m (.00005 in.) film thickness is 15.53 n (3.49 lbs) per pad for the primary seal and 11.65 (2.62 lbs) per pad for the secondary seal. The lift force decreases at .00000635 m (.00025 in.) to 4.083 n (.918 lb.) per pad on the primary seal and .069 n (.155 lb.) per pad on the secondary seal. The lift pads are not effective at operating gaps greater than approximately .0000127 m (.0005 in.). The relationship of lift force per pad and film thickness is shown in Fig. 4 .

TABLE 1. COMPARISON OF PRIMARY SEAL RING STRESS AND DEFLECTION AT 27580000 n/m^2 (4000 PSIA) AND 533 K (500 F)

	INCONEL X 750 CARBON G84	INCONEL X 750 AM CER MET	CARBON G84
INNER RING STRESS n/m^2 (PSI)	-103425000 (-15000)	-241325000 (-35000)	-37805285 (-5483)
OUTER RING STRESS n/m^2 (PSI)	59579695 (8641)	259362320 (37616)	---
TEMP. DIA. DEFLECTION m (IN.)	.00021 (.0083)	.00018 (.0073)	.00006 (.0025)
PRESS. DIA. DEFLECTION m (IN.)	-000012 (-.0005)	-000012 (-.0005)	-000106 (-.0042)
TOTAL DIA. DEFLECTION m (IN.)	.000198 (.0078)	.000172 (.0068)	-.000043 (-.0017)

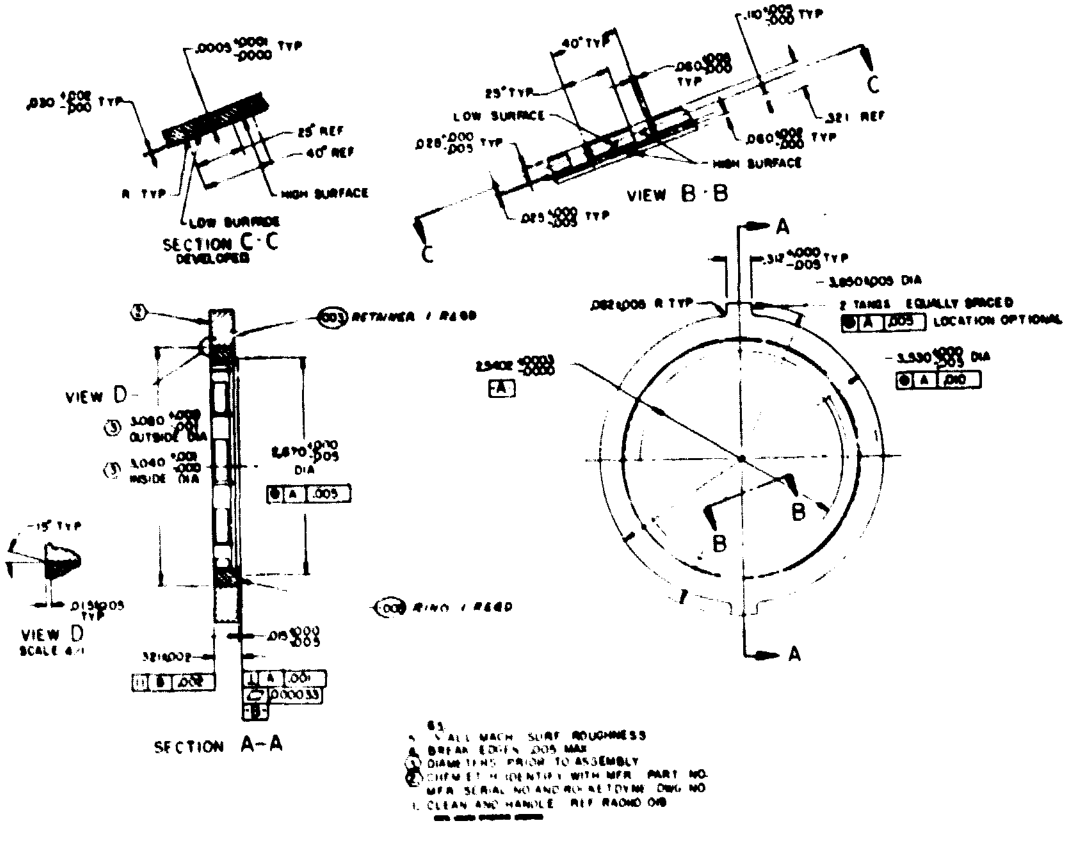


Figure 2. Rayleigh Step Pad Primary Seal Ring

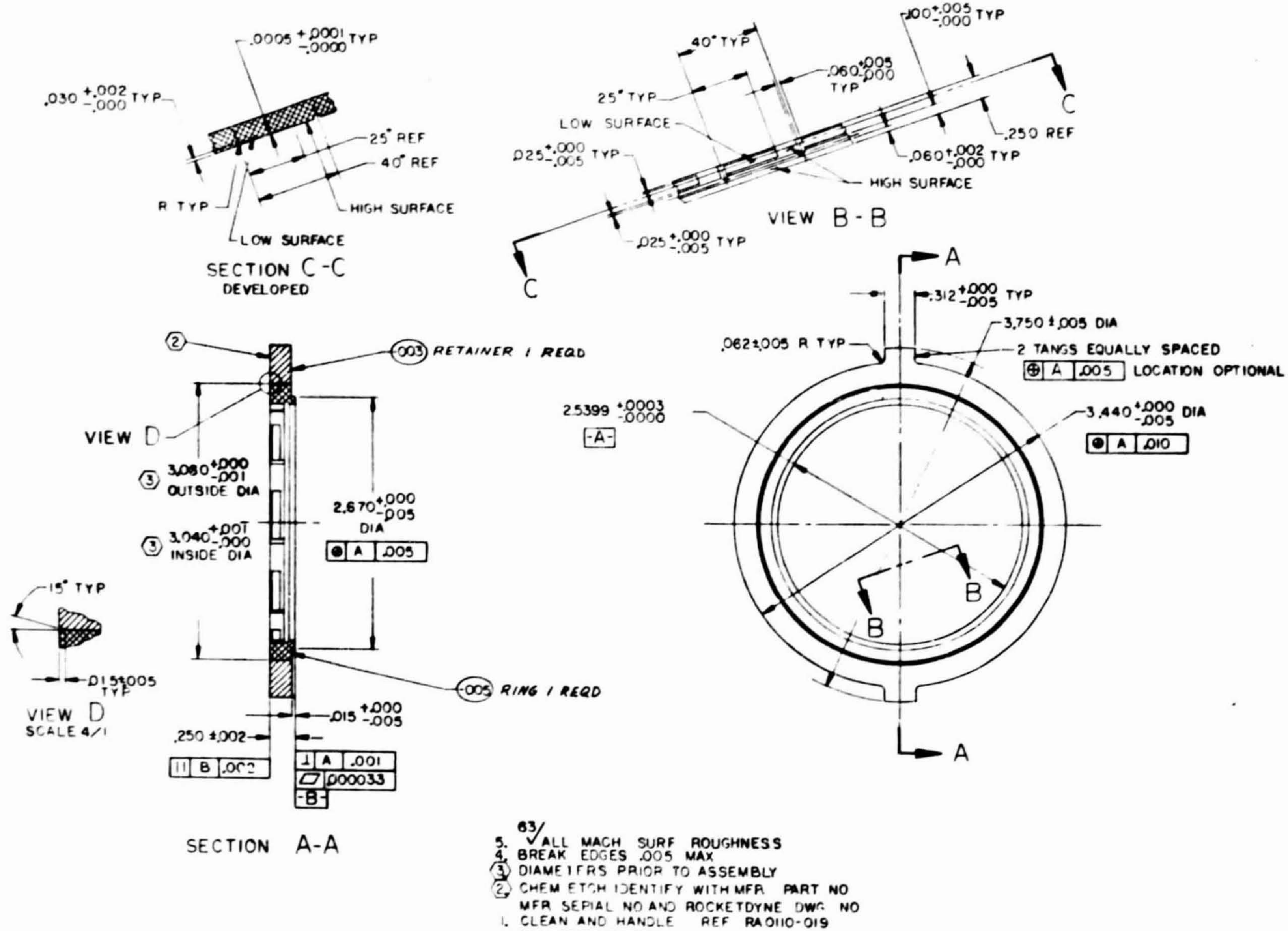


Figure 3. Rayleigh Step Pad Secondary Seal Ring

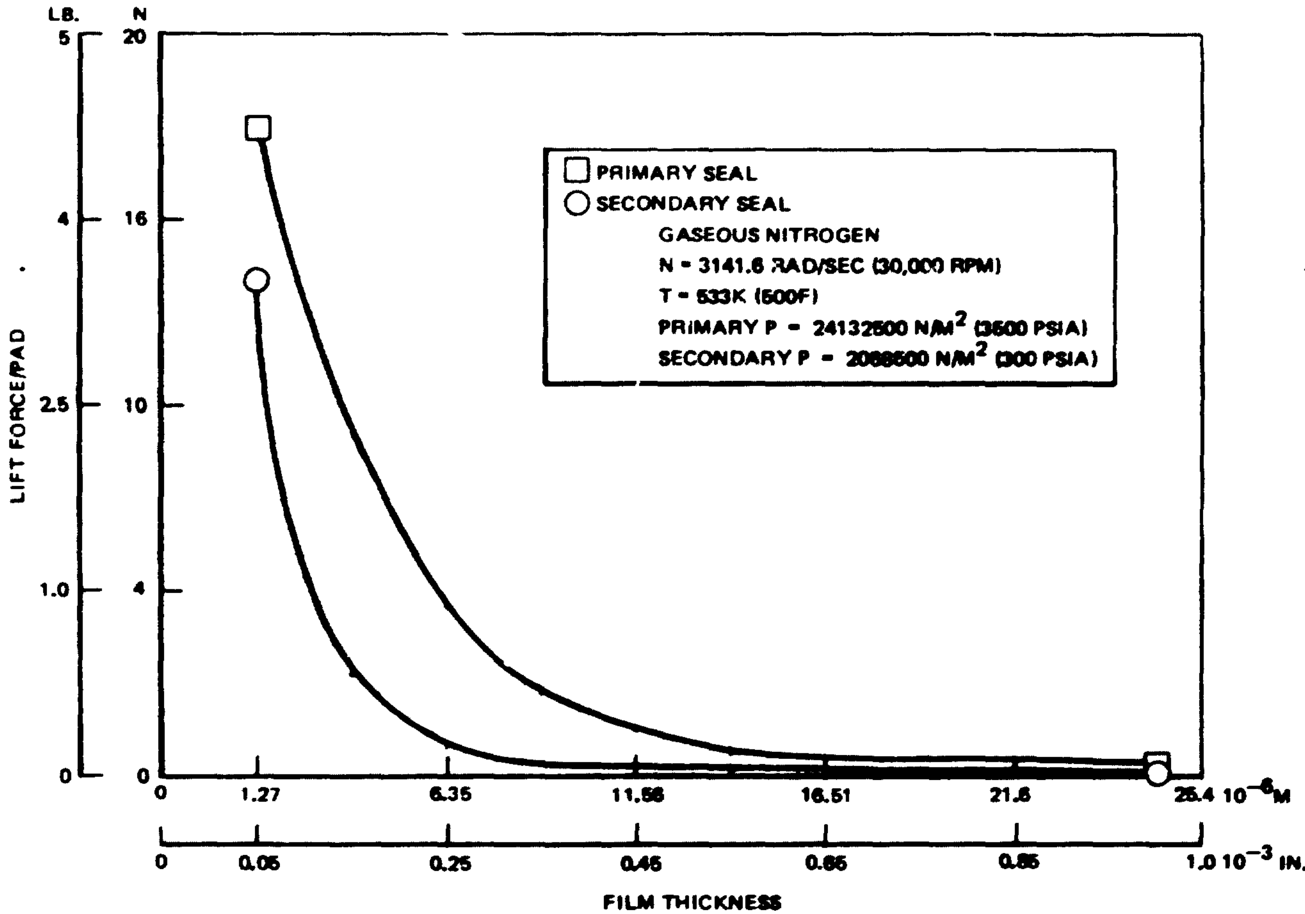


Figure 4. Rayleigh Step Lift Force per Pad vs Film Thickness

The lift pad film thickness varies around the circumferential seal ring from zero at the contact point to the diametral clearance oppósite the contact as shown in the following equation:

$$x = [R^2 + e^2 - 2Re \cos \theta]^{1/2} - r$$

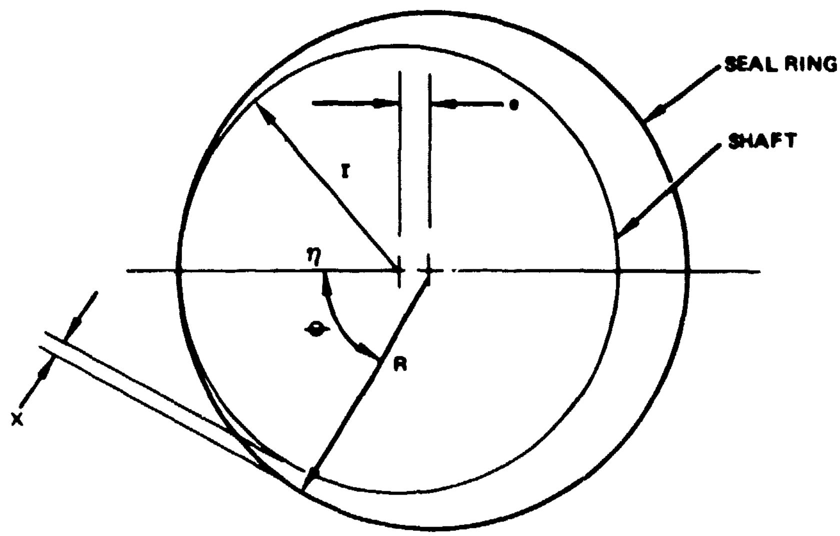
x = film thickness

R = seal ring inside radius

r = shaft outside radius

θ = angle from contact

e = eccentricity of seal ring and shaft



The film thickness as a function of the angle from the contact point for the test seal at .0000508 m (.0020 in.) diametral clearance is given below and shown in Fig. 5.

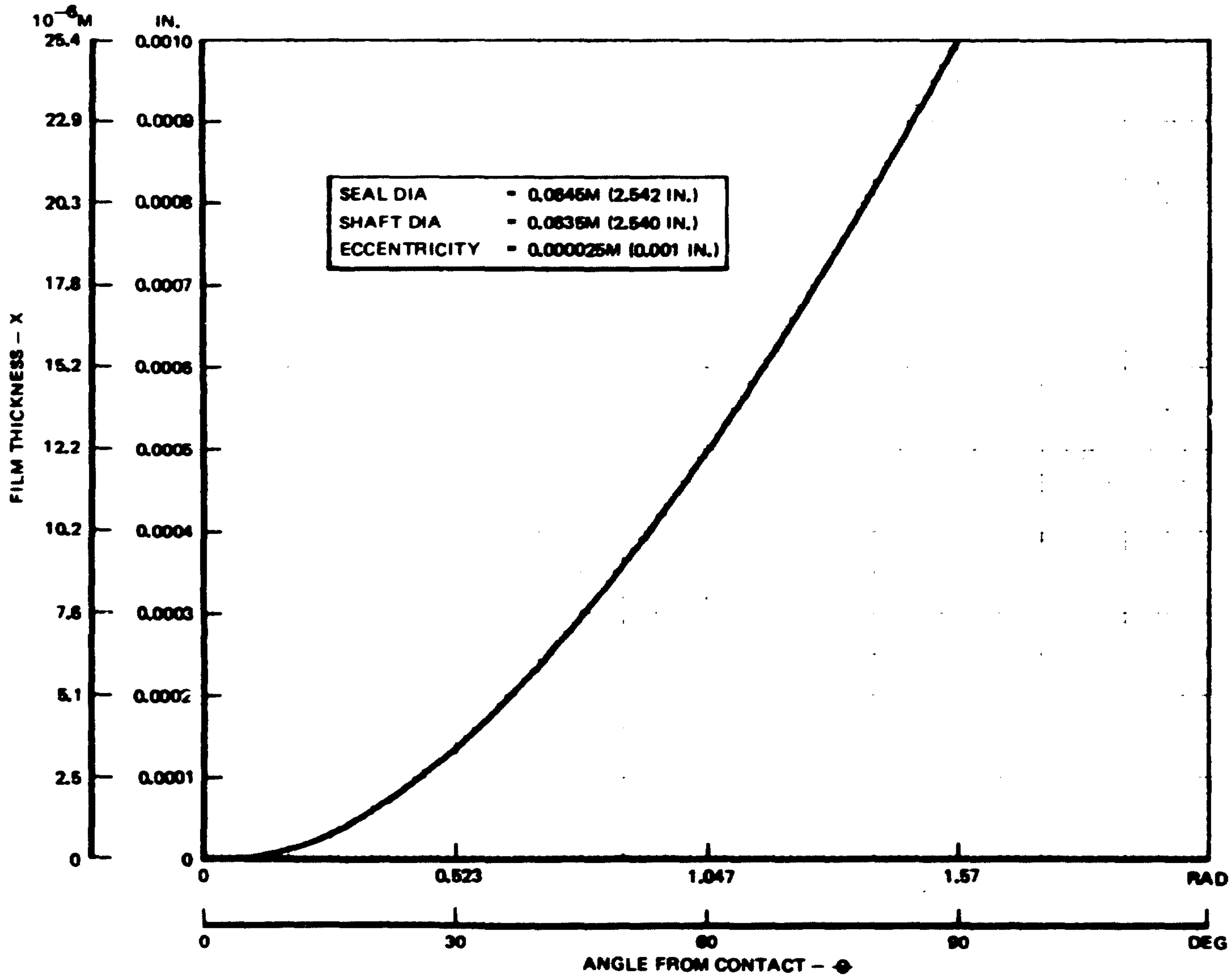
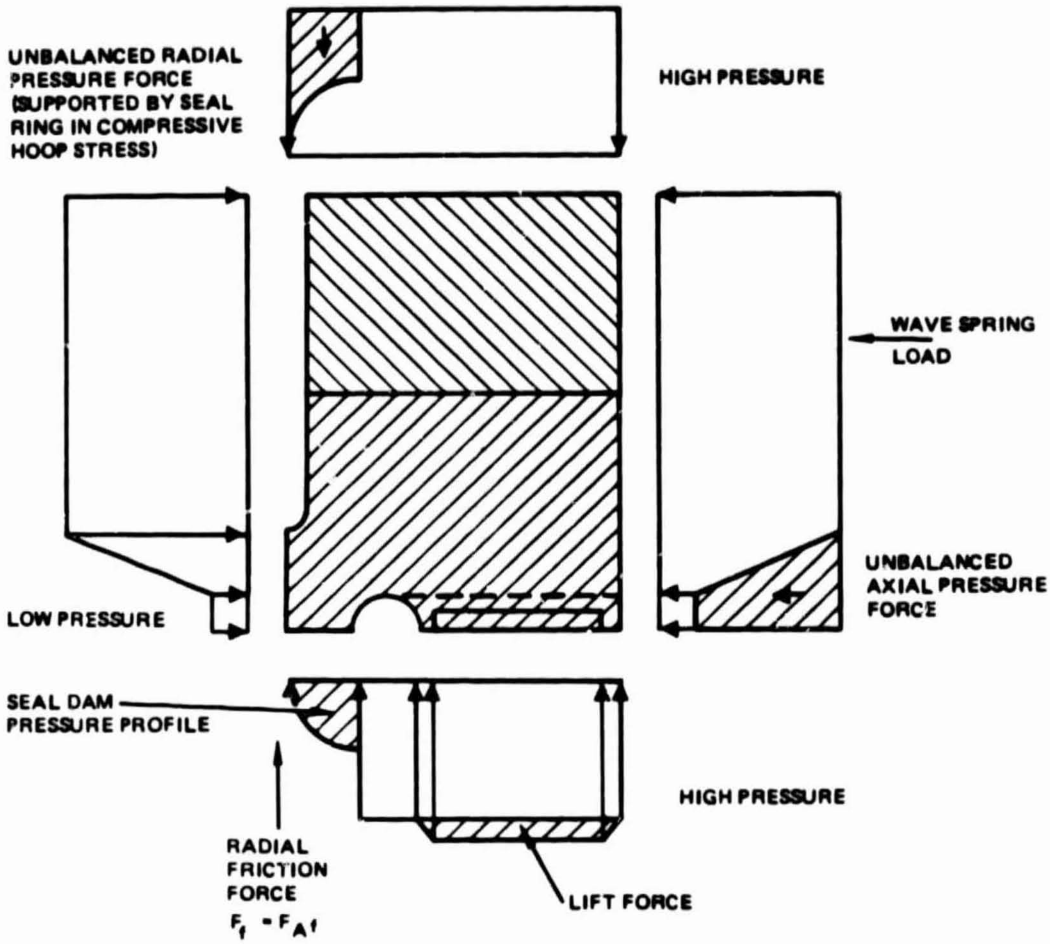


Figure 5. Seal Ring Film Thickness vs Angle From Contact

ANGLE θ		FILM THICKNESS x	
RAD	DEG	10^{-6}m	IN.
.262	15	0.864	.000034
.523	30	3.404	.000134
1.047	60	12.7	.0005
1.570	90	25.4	.001

A comparison of the lift force and film thickness to the angle from contact, indicates that only three pads provide significant lift force to assist in centering the seal ring. The maximum lift force is 23.6 n (5.3 lbs) for the primary seal and 16.5 n (3.7 lbs) for the secondary seal.

The ability of the seal ring to center on the shaft without rubbing contact depends on the lift force to exceed the radial friction force and dynamic inertia forces. The radial friction force is a function of the unbalanced axial forces and the coefficient of friction. The radial friction force for the test seal is 689 n (154 lbs) for the primary seal and 56.5 n (12.7 lbs) for the secondary seal. The analysis indicates that lift force is not sufficient to center the seal ring without rubbing contact. The Rayleigh step seal ring pressure profile and force summary is given in Fig. 6.



	PRIMARY	SECONDARY
HIGH PRESSURE - n/m^2 (PSIA)	24132500 (3500)	2068500 (300)
LOW PRESSURE – n/m^2 (PSIA)	2068500 (300)	344750 (50)
SEAL DAM AVERAGE PRESSURE - n/m^2 (PSIA)	10273550 (1490)	173754 (25.2)
WAVE SPRING LOAD - n/m^2 (LB)	22 (5)	22 (5)
AXIAL PRESSURE FORCE - n (LB)	4541 (1021)	354 (79.7)
TOTAL AXIAL FORCE - n(LB)	4564 (1026)	377 (84.7
RADIAL FRICTION FORCE - n (LB)	689 (154)	56.5 (12.7)
MAXIMUM LIFT FORCE - n (LB)	23.6 (5.31)	16.5 (3.7)

Figure 6. Rayleigh Step Seal Ring Pressure Profile and Force Summary

THERMAL ANALYSIS

A thermal analysis of the tester seal area was performed to establish the temperature profile for a finite element analysis. Three-dimensional thermal models were employed to determine the temperature distribution in the shaft, bearing, oil seal, hot-gas seal sleeve, and flywheel areas of the tester assembly under steady-state operating conditions. Heating is assumed to occur from the hot-gas seal leakage with additional thermal input from the frictional components of the oil seal and ball bearings. The primary heat sink is provided by heat transfer from the stepped area of the rotating shaft to the lubricating oil environment in the central casing.

The steady-state temperature distribution throughout the region of interest is shown on Fig. 7 . Heat inputs to the shaft include the total frictional heating from the oil seal and three % of the total estimated bearing power (or 60% of the bearing frictional component). The remainder of the bearing power is assumed to be absorbed in viscous shear heating of the lubricating oil with 40% of frictional heating transferred to the outer bearing race.

STRESS AND DEFLECTION ANALYSIS

A finite element analysis of the seal rings and shaft sleeve to determine the operating stresses and displacements was performed. The analysis was performed for operation at room temperature and at the operating temperature of 533K (500 F). Results of the seal ring analysis are shown in Fig. 8 and 9 .

The finite element analysis indicates that the primary seal ring radial displacement at 27580000 n/m^2 (4000 psia) and 553K (500 F) varies from .000103 m (.004059 in.) to .000104 m (.004104 in.) across the dam and from .000104 m (.004102 in.) to .0001047 m (.004125 in.) across the lift pads. The dam surface has .0000011 m (.000045 in.) divergent taper. The lift pad surface variation is .0000005 m (.000023 in.). The carbon material will allow the seal ring to wear-in for exact conformance at operating conditions.

The secondary seal ring radial displacement varies from .0001076 m (.004239 in.) to .0001077 m (.004244 in.) with a convergent taper of .0000001 m (.000005 in.) across the dam. The lift pad displacement is constant at .0001078 m (.004247 in.).

The finite element analysis of the shaft sleeve was refined to determine the effect of the initial interference between the sleeve and shaft on the operating displacement of the sleeve. The sleeve is installed on the shaft with 0000025 m to .0000127 m (.0001 in. to .0005 in.) radial interference. The radial displacements of the sleeve outer surface from the free position prior to installation to the operating conditions are shown in Fig. 10 and 11 for room temperature operation, and in Fig. 12 and 13 for high-temperature operation.

Final seal and sleeve diameters, displacements, and clearances for the different seal positions are summarized in Table 2 for English units and Table 3 for SI units. The seal-to-sleeve diametral clearance varies from .000035 m (.0014 in.) to .000058 m (.0023 in.) for 294K (70 F) operation and from .00048 m (.0019 in.) to .000076 m (.0030 in.) for 533K (500 F) operation.

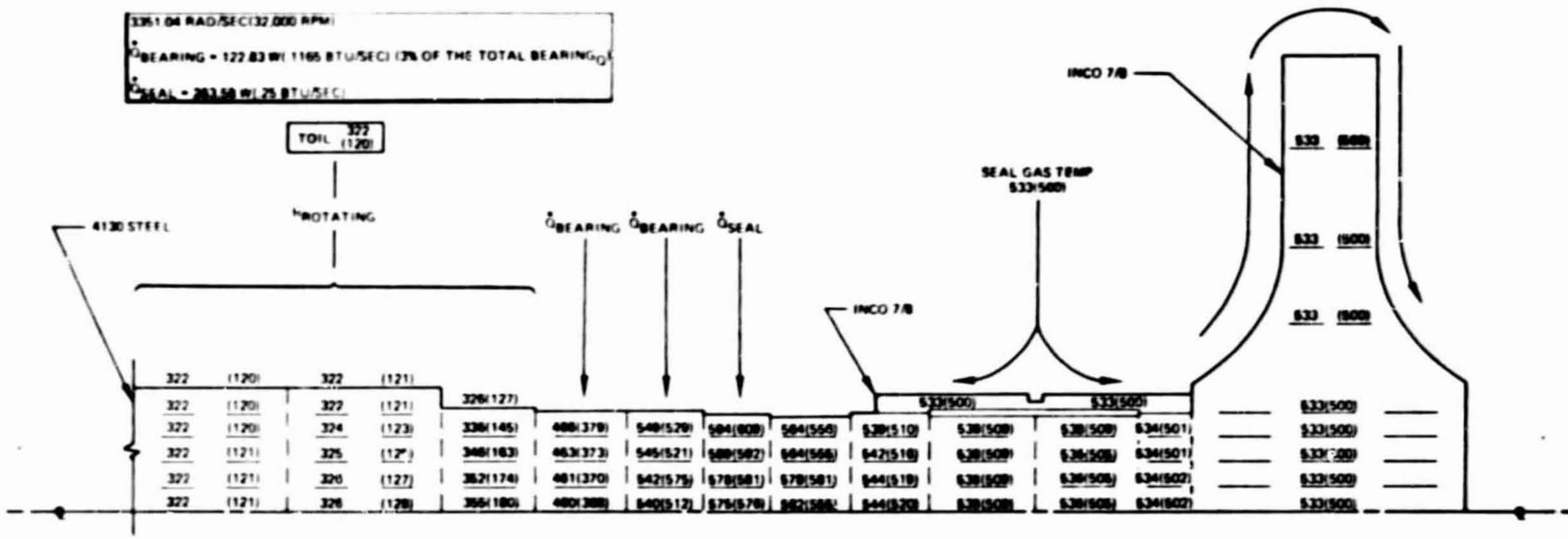


Figure 7. Steady-State Temperature Distribution of Tester Seal Area - K (F)

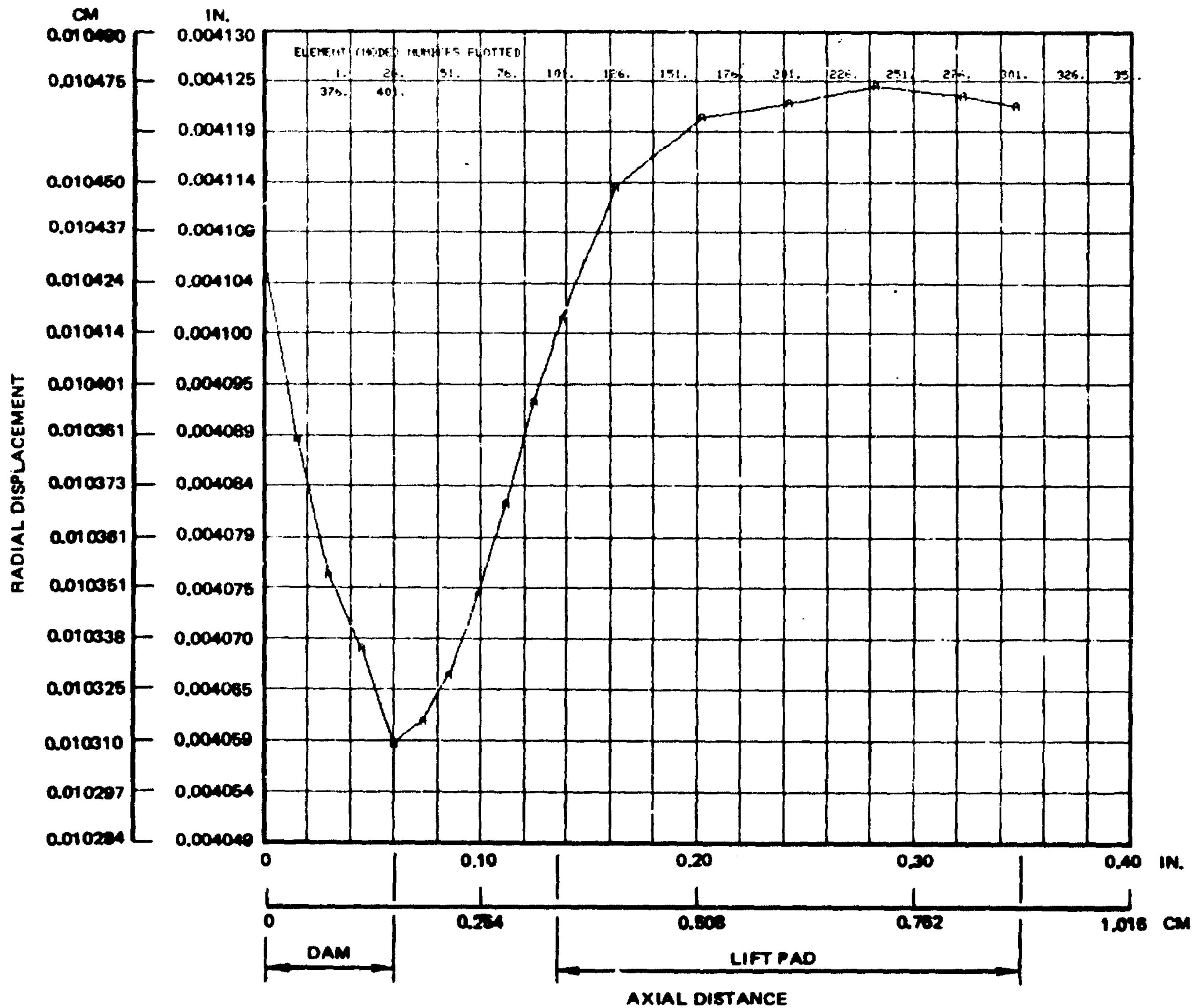


Figure 8. Primary Seal Ring Radial Displacement at 27580000 n/m^2 at (4000 psia) and 533 K (500 F) (Inconel x 750/Carbon G84)

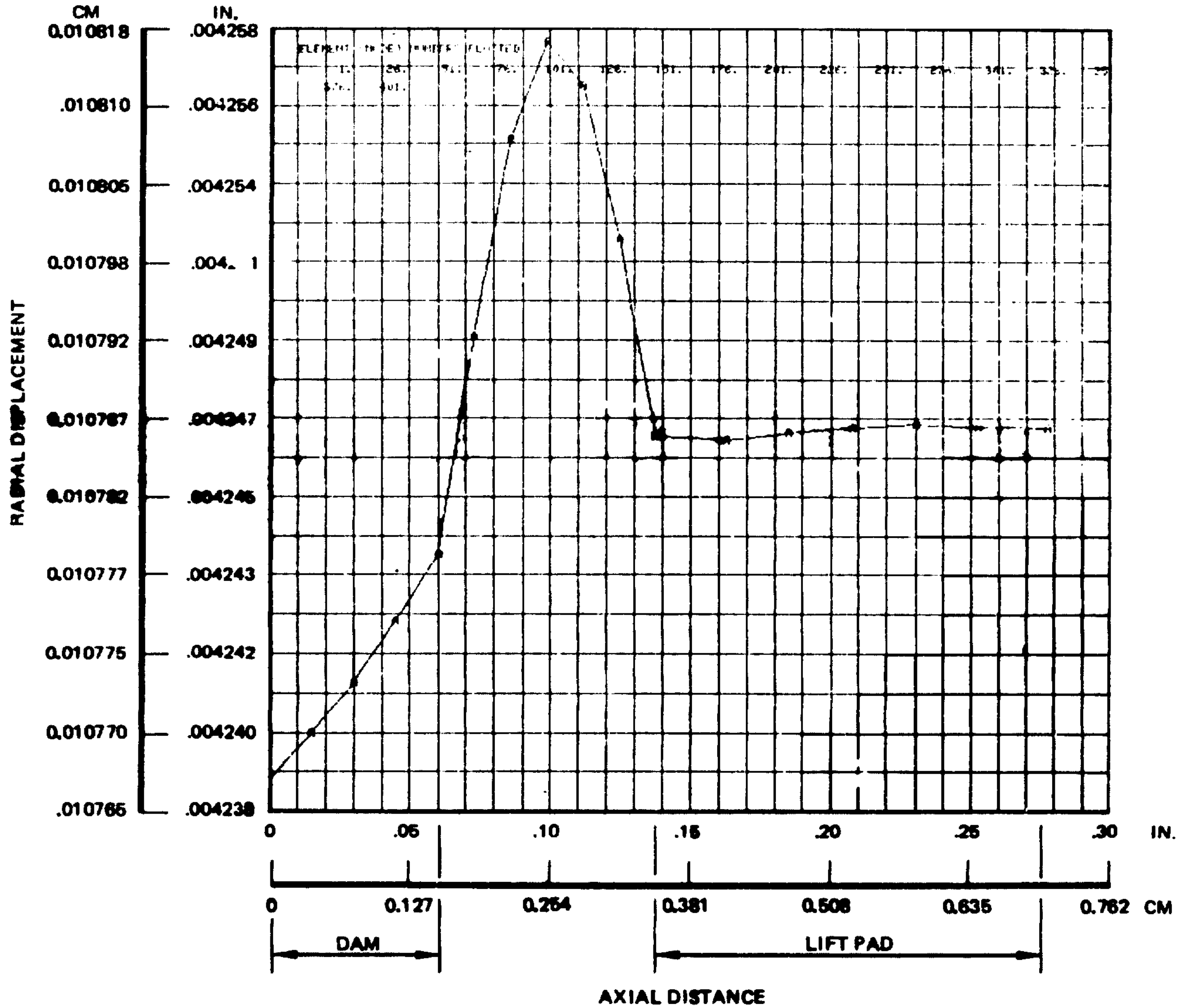


Figure 9. Secondary Seal Ring Radial Displacement at 586000 n/m^2 at (85 psia) and 533 K (500 F) (Inconel x 750/Carbon G84)

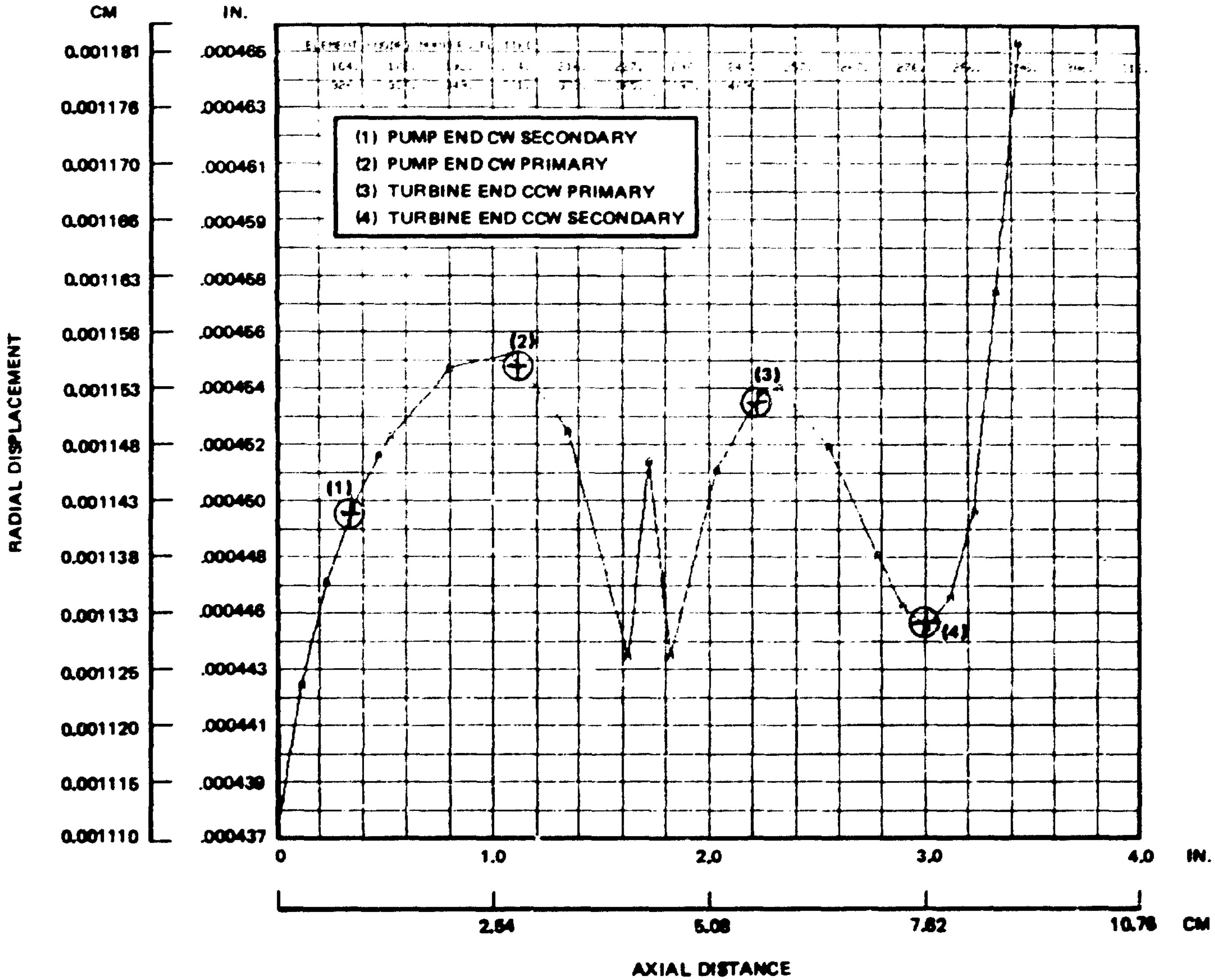


Figure 10. Sleeve Total Radial Displacement From Free Position to Operation at 294 K (70 F) and 3351 rad/sec (32,000 rpm) With .0000025 m (.0001-Inch) Radial Interference

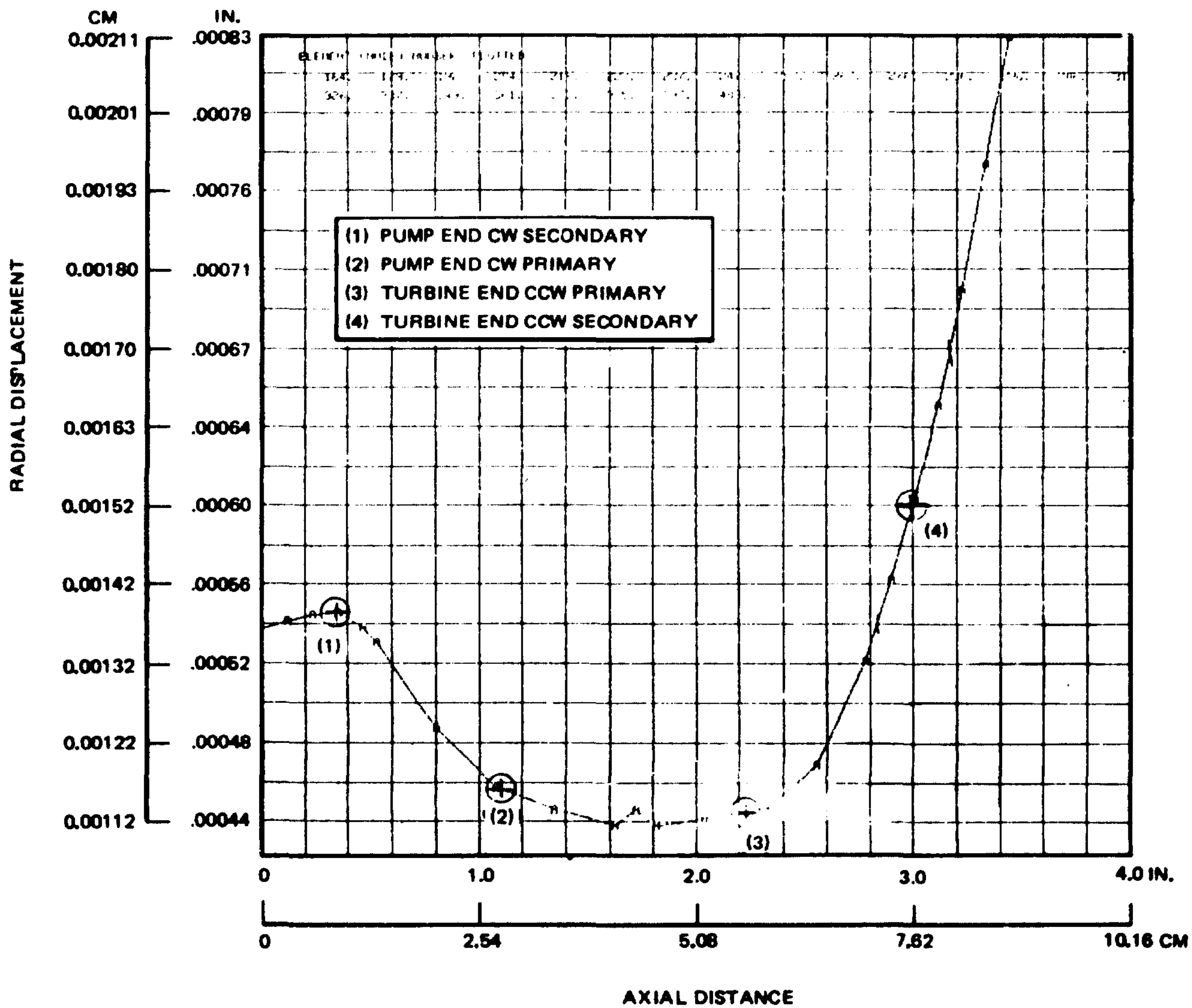


Figure 11. Sleeve Total Radial Displacement From Free Position to Operation at 294 K (70 F) and 3351 rad/sec (32,000 rpm) With .000012 m (.0005-Inch) Radial Interference

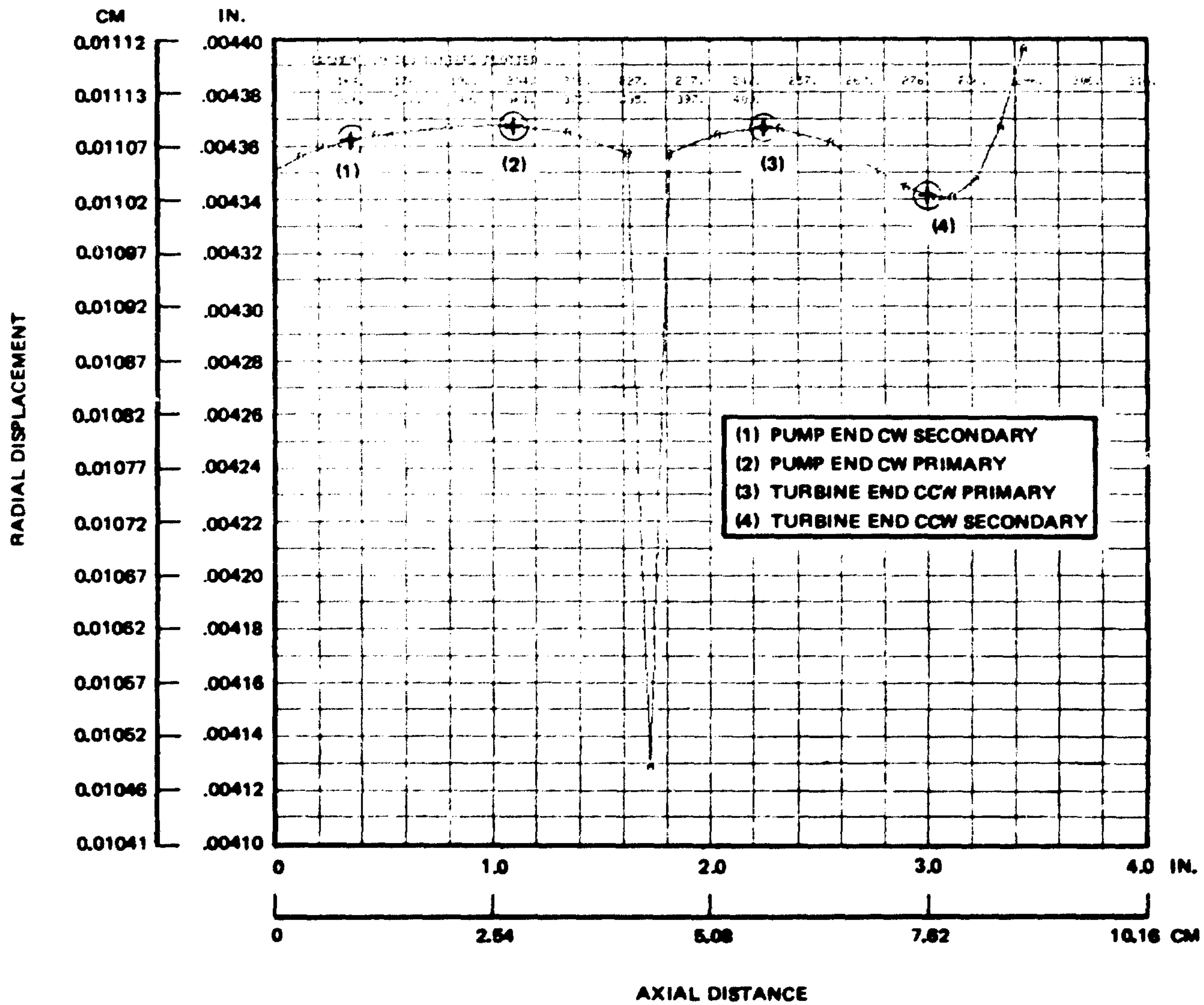


Figure 12. Sleeve Total Radial Displacement From Free Position to Operation at 533 K (500 F) and 3351 rad/sec (32,000 rpm) With .0000025 m (.0001-Inch) Radial Interference

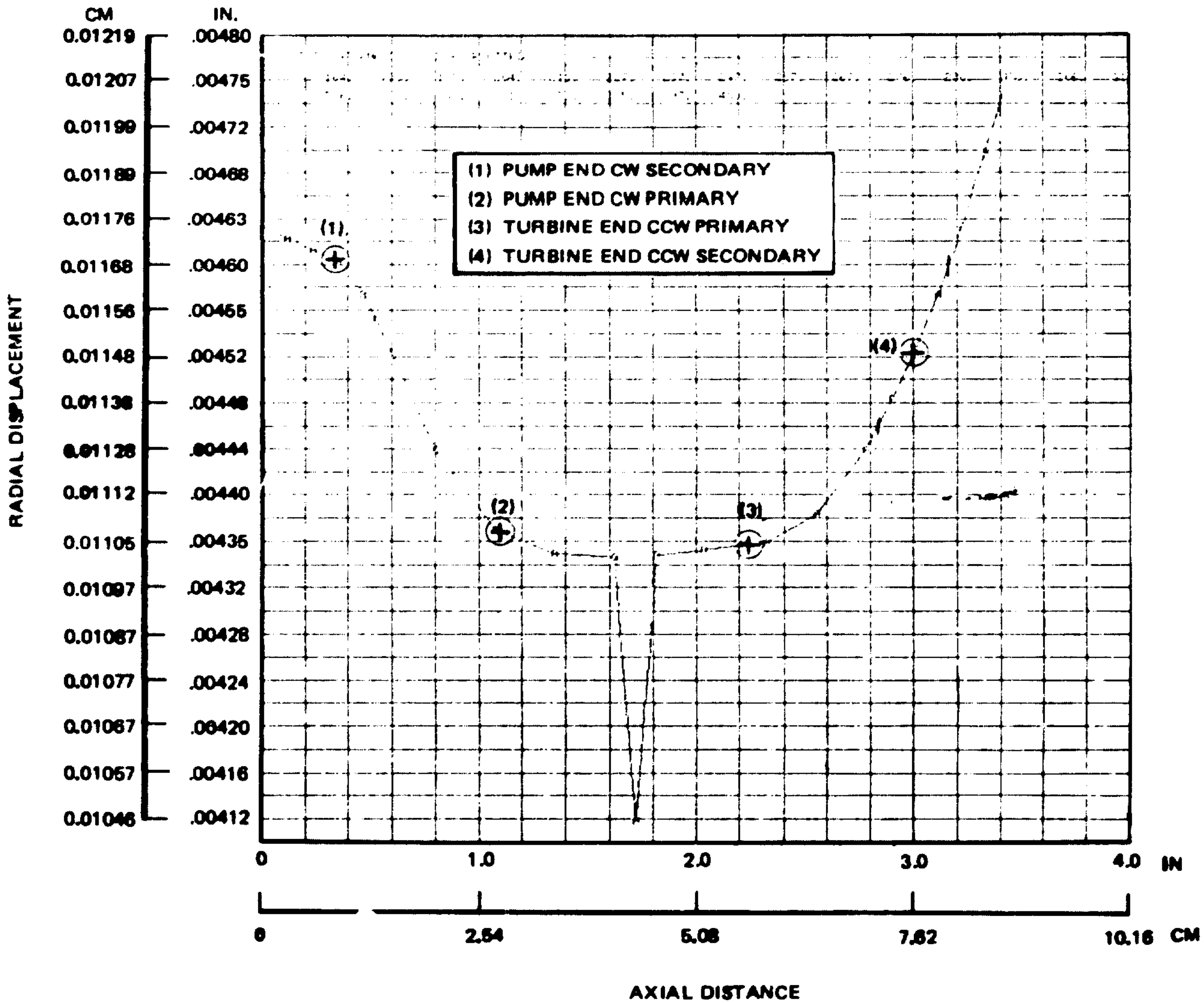


Figure 13. Sleeve Total Radial Displacement From Free Position to Operation at 533 K (500 F) and 3351 rad/sec (32,000 rpm) With .000012 m (.0005-Inch) Radial Interference

TABLE 2. RAYLEIGH STEP SEAL AND SLEEVE DIAMETERS, DISPLACEMENT AND CLEARANCES-U.S. CUSTOMARY UNITS

	PUMP END				TURBINE END			
	(1) cw Secondary		(2) cw Primary		(3) ccw Primary		(4) ccw Secondary	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
FREE CONDITION								
Sleeve O.D. (in.)	2.5373	2.5370	2.5373	2.5370	2.5373	2.5370	2.5373	2.7370
INSTALLED AMBIENT								
(a) Sleeve ΔD (in.)	.0009	.002	.001	.0000	.0000	.0000	.0008	.0002
Sleeve O.D. (in.)	2.5382	2.5372	2.5374	2.5370	2.5373	2.5370	2.5381	2.5372
Seal I.D. (in.)	2.5402	2.5399	2.5405	2.5402	2.5405	2.5402	2.5402	2.5399
Clearance Dia. (in.)	.0030	.0017	.0035	.0028	.0035	.0029	.0030	.0018
OPERATING 70°F & 32000 RPM								
(b) Sleeve ΔD (in.)	.0011	.0009	.0009	.0009	.0009	.0009	.0012	.0009
Sleeve O.D. (in.)	2.5384	2.5379	2.5382	2.5379	2.5382	2.5379	2.5385	2.5379
(b) Seal ΔD (in.)	.0000	.0000	-.0005	-.0005	-.0005	-.0005	.0000	.0000
Seal I.D. (in.)	2.5402	2.5399	2.5400	2.5397	2.5400	2.5397	2.5402	2.5399
Clearance Dia. (in.)	.0023	.0015	.0021	.0015	.0021	.0015	.0023	.0014
OPERATING 500°F & 32000 RPM								
(b) Sleeve ΔD (in.)	.0092	.0087	.0087	.0087	.0087	.0087	.0090	.0087
Sleeve O.D. (in.)	2.5465	2.5457	2.5460	2.5457	2.5460	2.5457	2.5463	2.5457
(b) Seal ΔD (in.)	.0085	.0085	.0081	.0081	.0081	.0081	.0085	.0085
Seal I.D. (in.)	2.5487	2.5484	2.5486	2.5486	2.5486	2.5483	2.5487	2.5484
Clearance Dia. (in.)	.0030	.0019	.0029	.0023	.0029	.0023	.0030	.0021

(a) Diametral displacement from free position to installed position

(b) Diametral displacement from free position to operating condition

TABLE 3. RAYLEIGH STEP SEAL AND SLEEVE DIAMETERS, DISPLACEMENTS AND CLEARANCES-SI UNITS

	PUMP END				TURBINE END			
	(1) cw Secondary		(2) cw Primary		(3) ccw Primary		(4) ccw Secondary	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
FREE CONDITION								
Sleeve O.D. (m.)	.06444742	.0644398	.06444742	.0644398	.06444742	.0644398	.06444742	.0644398
INSTALLED AMBIENT								
(a) Sleeve ID (m.)	.000022	.000005	.000002	.0000	.0000	.0000	.000020	.000005
Sleeve O.D. (m.)	.06447028	.06444488	.06444996	.0644398	.06444742	.0644398	.06446774	.06444488
Seal I.D. (m.)	.06452108	.06451346	.00163902898	.06452108	.00163902898	.06452108	.06452108	.06451346
Clearance Dia. (m.)	.0000762	.00004318	.0000889	.00007112	.0000889	.00007366	.0000762	.00004572
OPERATING 294K 32000 RPM								
(b) Sleeve ID (m.)	.00002794	.000022	.000022	.000022	.000022	.000022	.00003048	.000022
Sleeve O.D. (m.)	.06447536	.06446266	.06447028	.06446266	.06447028	.06446266	.0644779	.06446266
(b) Seal ID (m.)	.0000	.0000	-.0000127	-.0000127	-.0000127	-.0000127	.0000	.0000
Seal I.D. (m.)	.064652108	.06451346	.064516	.06450838	.064516	.06450838	.06451346	.06451346
Clearance Dia. (m.)	.00005842	.0000381	.00005334	.0000381	.00005334	.0000381	.00005842	.00003556
OPERATING 533K & 32000 RPM								
(b) Sleeve ID (m.)	.00023368	.00022098	.00022098	.00022098	.00022098	.00022098	.0002286	.00022098
Sleeve O.D. (m.)	.0646811	.06466078	.0646684	.06466078	.0646684	.06466078	.06467602	.06466078
(b) Seal ID (m.)	.0002159	.0002159	.00020574	.00020574	.00020574	.00020574	.0002159	.0002159
Seal I.D. (m.)	.06473698	.06447536	.06473444	.06473444	.06473444	.06472682	.06473698	.06447536
Clearance Dia (m.)	.0000762	.00004826	.00007366	.00005842	.00007366	.00005842	.00004826	.00005334

(a) Diametral displacement from free position to installed position

(b) Diametral displacement from free position to operating condition

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Seal diameters were established based on the final finite element analysis to provide a nominal diametral clearance of .00005 m (.0020 in.). The same seal design was used for both the 294K (70 F) and 533K (500 F) tests. The same seal diameters were used for the cw (pump end) and ccw (turbine end) positions.

LEAKAGE AND PRESSURE PROFILE ANALYSIS

Gaseous nitrogen leakage rate at 533K (500 F) and 27580000 n/m^2 (4000 psia) was calculated using conventional isentropic compressible flow data and the NASA program for quasi-one-dimensional compressible flow with friction and parallel films (Ref 2). The two methods agree within 6.4% using an entrance loss coefficient of .6, and a radial gap or film thickness of .00005 m (.002 in.). The results are given below and in Fig. 14 and 15.

	Primary	Secondary
Isentropic Leakage SCMM (SCFM)	15.06 (532)	.320 (11.3)
QUASC Leakage SCMM (SCFM)	14.16 (500)	.303 (10.7)

Secondary seal leakage was computed using the primary seal drain pressure or secondary seal upstream pressure 586075 n/m^2 (85 psia) which would result from the relative flow areas of the primary drain and secondary seal.

The sealing interface pressure distribution was computed using the NASA program for quasi-one-dimensional compressible flow (Fig. 16 and 17). A loss coefficient of .6, and a film thickness of .00005 m (.002 in.) were assumed. The pressure profiles were used for the seal ring stress and deflection calculations.

HYDROSTATIC TAPERED BORE

The convergent tapered bore seal ring produces a hydrostatic pressure centering force to center the seal ring without rubbing contact. This hydrostatic force is developed by the pressure differential across the seal and is a function of the clearance. Variation of the pressure profile with the clearance gap results in an unbalanced radial force. The radial force is higher for smaller gaps and lower for larger gaps; therefore, as the seal ring eccentricity increases, the unbalanced radial force on the side approaching rubbing contact causes the ring to be pushed back toward center. The seal ring will seek an equilibrium position where the clearance gap is constant.

The tapered bore analysis was performed by NASA using the methods described in Ref. 3. The analysis assumes the following:

1. Perfect gas

2. Eccentricity is small compared to the clearance

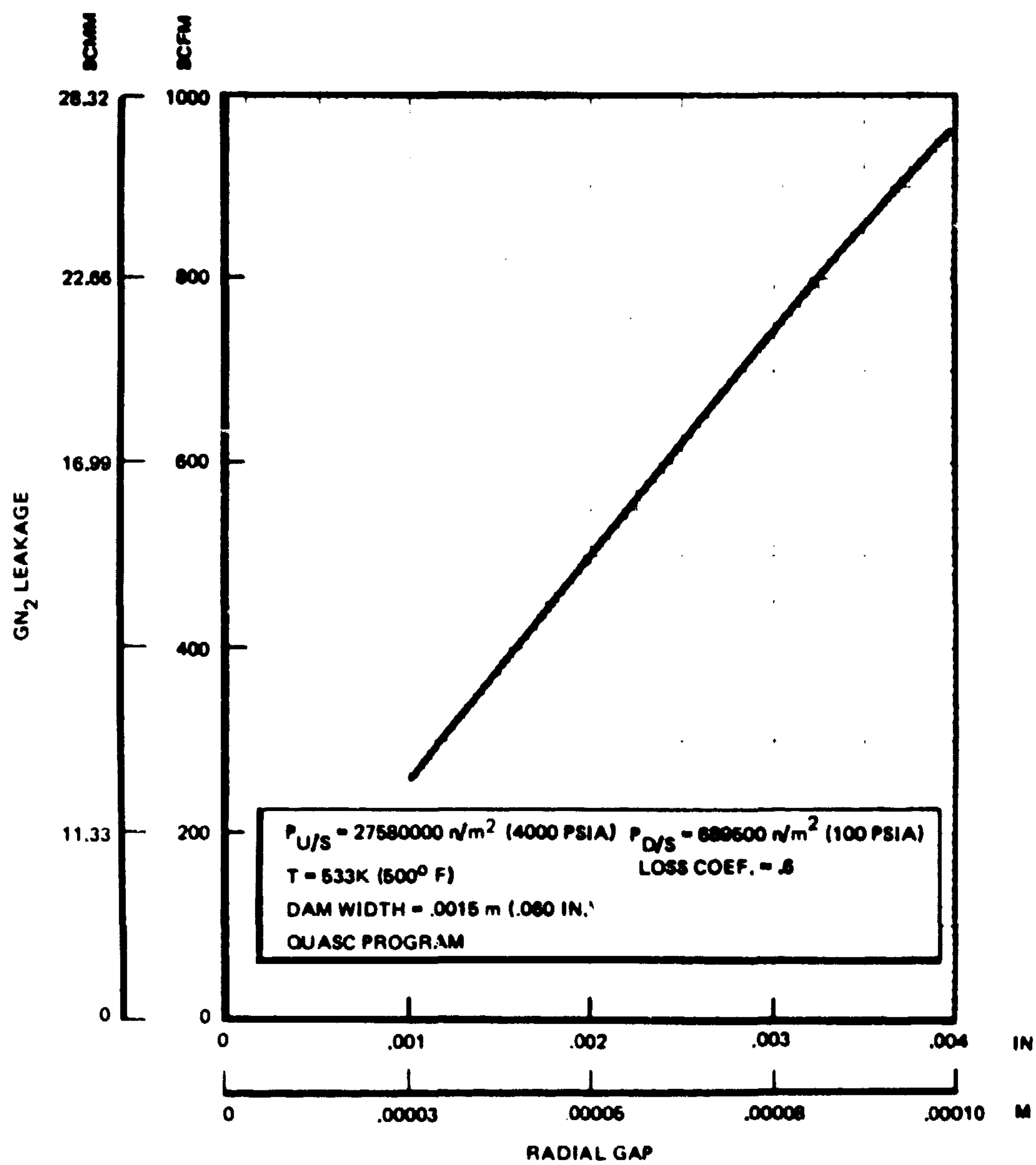

Figure 14. Rayleigh Step Primary Seal Calculated GN_2 Leakage

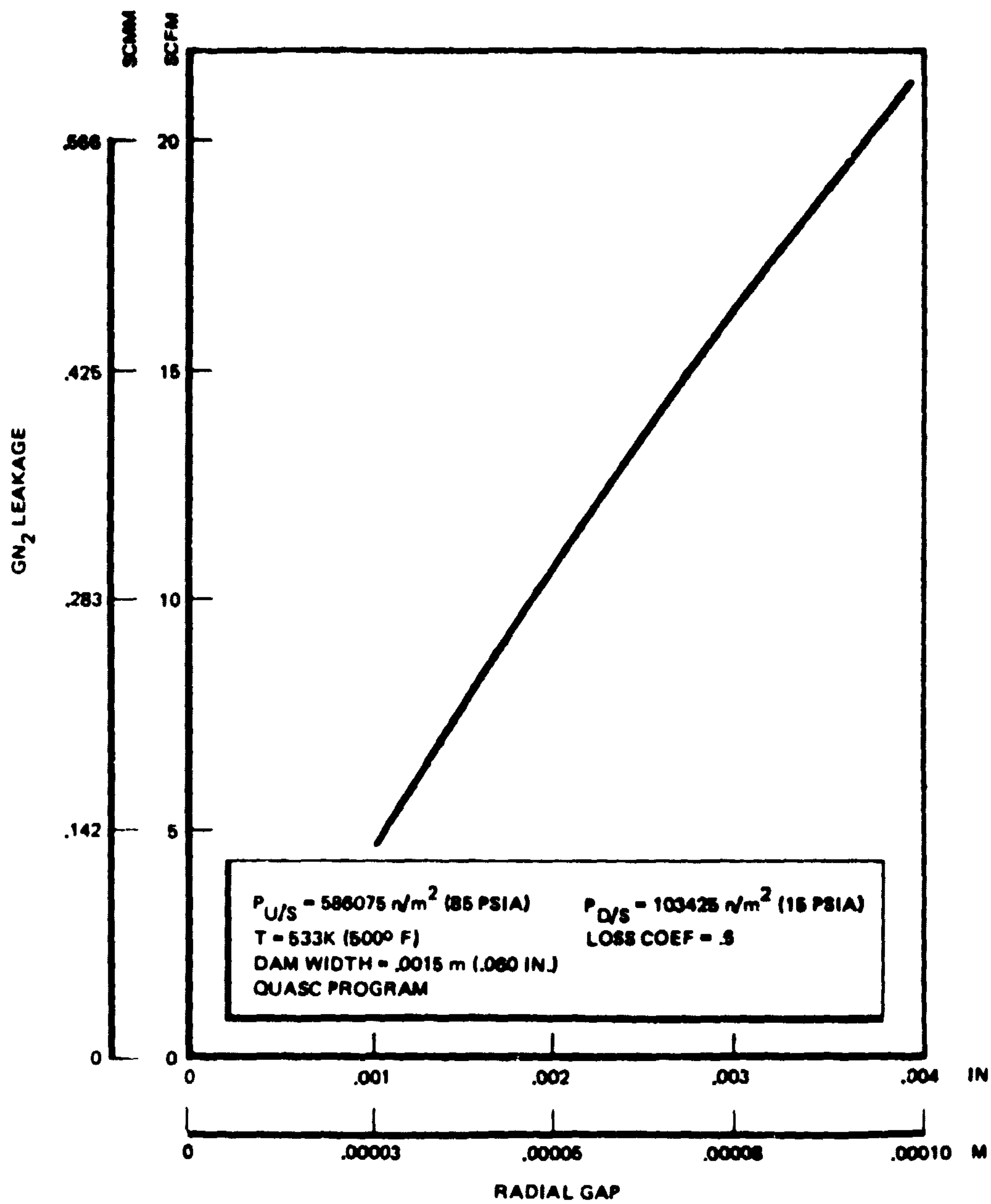

Figure 15. Rayleigh Step Secondary Seal Calculated GN_2 Leakage

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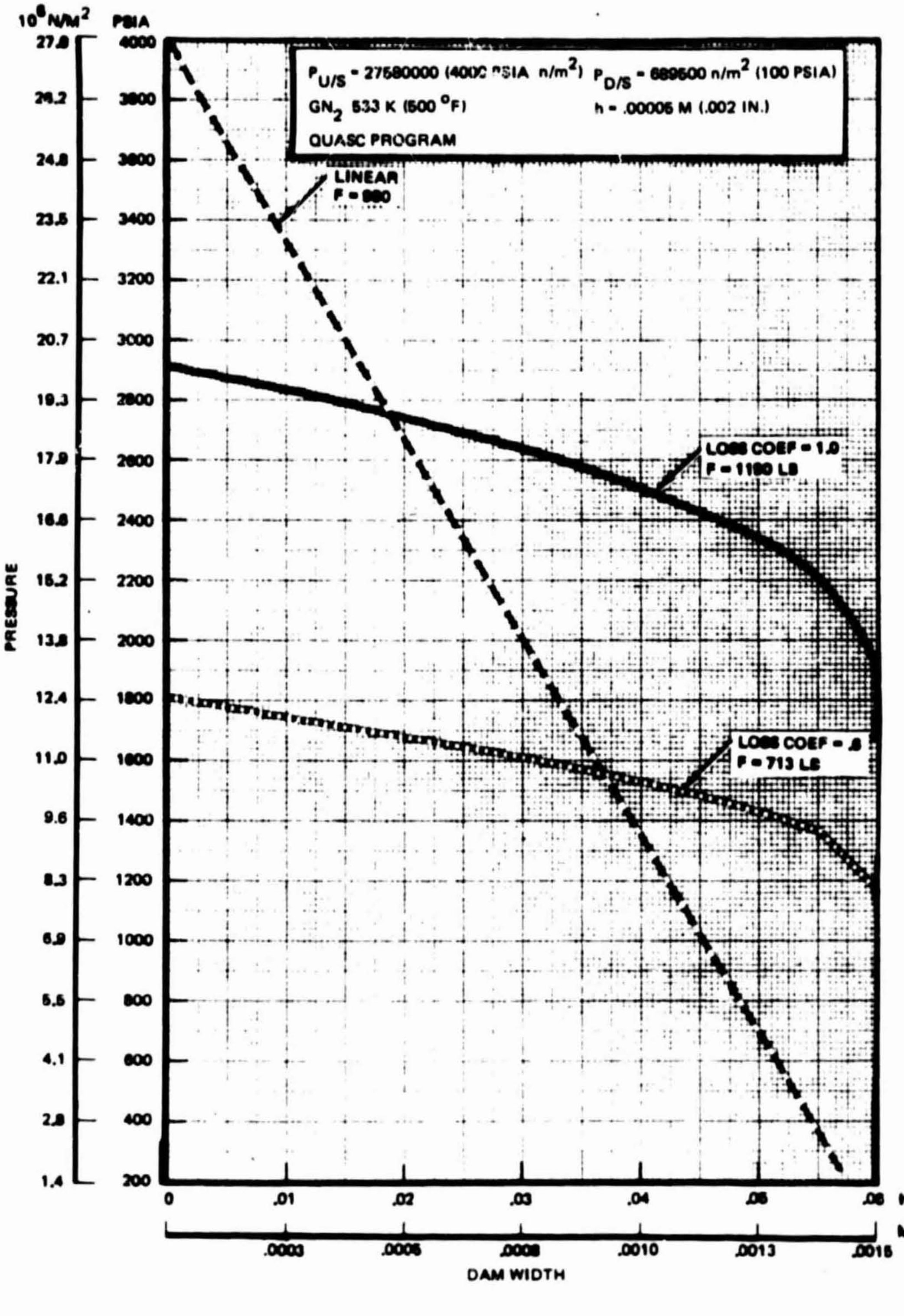

Figure 16. Rayleigh Step Primary Seal Dam Pressure Profile

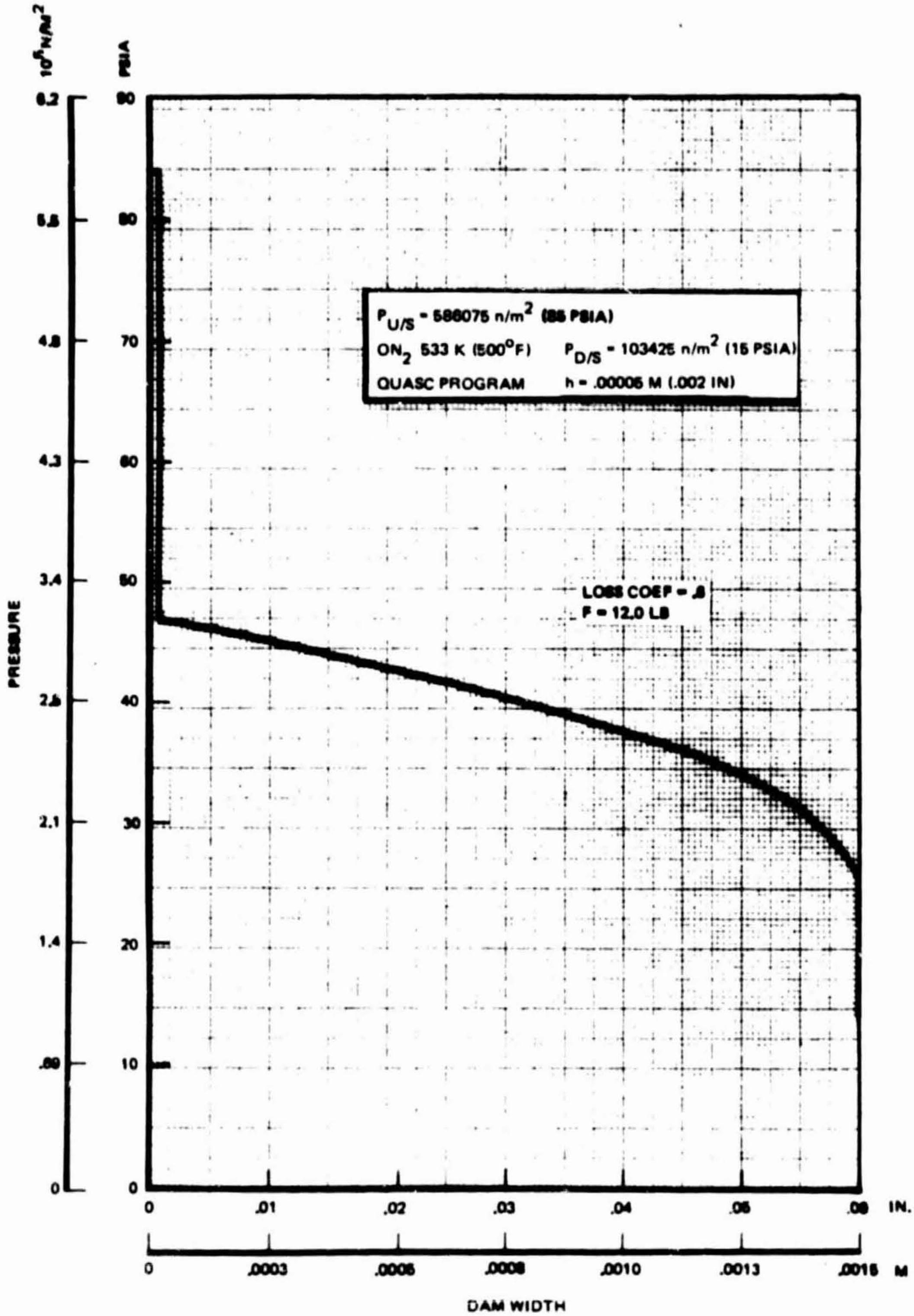

Figure 17. Rayleigh Step Secondary Seal Dam Pressure Profile

3. No rotational effects

4. Fluid flow is one-dimensional in axial direction

5. Constant friction factor

The analysis procedure used was to calculate the pressure distribution along an axial element of the seal ring and determine total centering force by integrating over the tapered bore area. The solution with the assumed conditions is the same as that for flow between flat plates. The solution can also be expressed in terms of the radial stiffness or spring rate of the fluid film in the clearance gap of the tapered bore. Analysis procedures were implemented on a digital computer for solution. A detail design of the tapered bore seal rings is shown in Fig. 18 and 19.

The amount of taper or ratio of the inlet clearance to the outlet clearance (Fig. 20) was optimized to maximize the ratio of fluid film stiffness to seal leakage. The optimization results in a film stiffness only slightly less than maximum, while reducing leakage. The optimum clearance ratio is 1.8 for both the primary and secondary seals. The relationship of radial fluid film stiffness to the seal clearance ratio is shown in Fig. 21 for the primary seal and in Fig. 22 for the secondary seal.

The leakage for a tapered seal is approximately 27% higher at a clearance ratio of 1.8 compared to the leakage through a straight bore seal. The theoretical gaseous nitrogen leakage on the primary seal at 24132599 n/m^2 (3500 psia) and 533K (500 F) is .599 kg/sec (1.32 lb/sec). Secondary seal leakage as a function of the clearance ratio is shown in Fig. 23.

The seal ring materials were changed on the tapered bore seal to provide for a maximum temperature of 811K (1000 F). The metal retainer band was changed from Inconel 750 to Inconel 903 due to its lower thermal expansion rate. The carbon material was changed from G84 to P5N due to its higher temperature resistance. The lower thermal expansion of the retainer band is required to prevent loss of the interference fit at higher temperature.

The primary seal ring small-end clearance was established to provide a minimum of .00005 m (.002 in.) diametral clearance at operating conditions of 26201000 n/m^2 (3800 psia) and 533K (500 F). The diametral deflections are plus .000111 m (.0044 in.) due to temperature and minus .000078 m (.0031 in.) due to pressure. The shaft sleeve growth due to temperature and speed is .000228 m (.0090 in.); therefore, the total diametral clearance differential at operating conditions is minus .000195 m (.0077 in.). The ambient installed diametral clearance on the small end is .000246 m to .000261 m (.0097 to .0103 in.)

Secondary seal ring clearance and deflection are the same as the primary, except the pressure deflection is negligible due to the lower pressure, 965300 n/m^2 (140 psia). The total diametral clearance differential at operating conditions

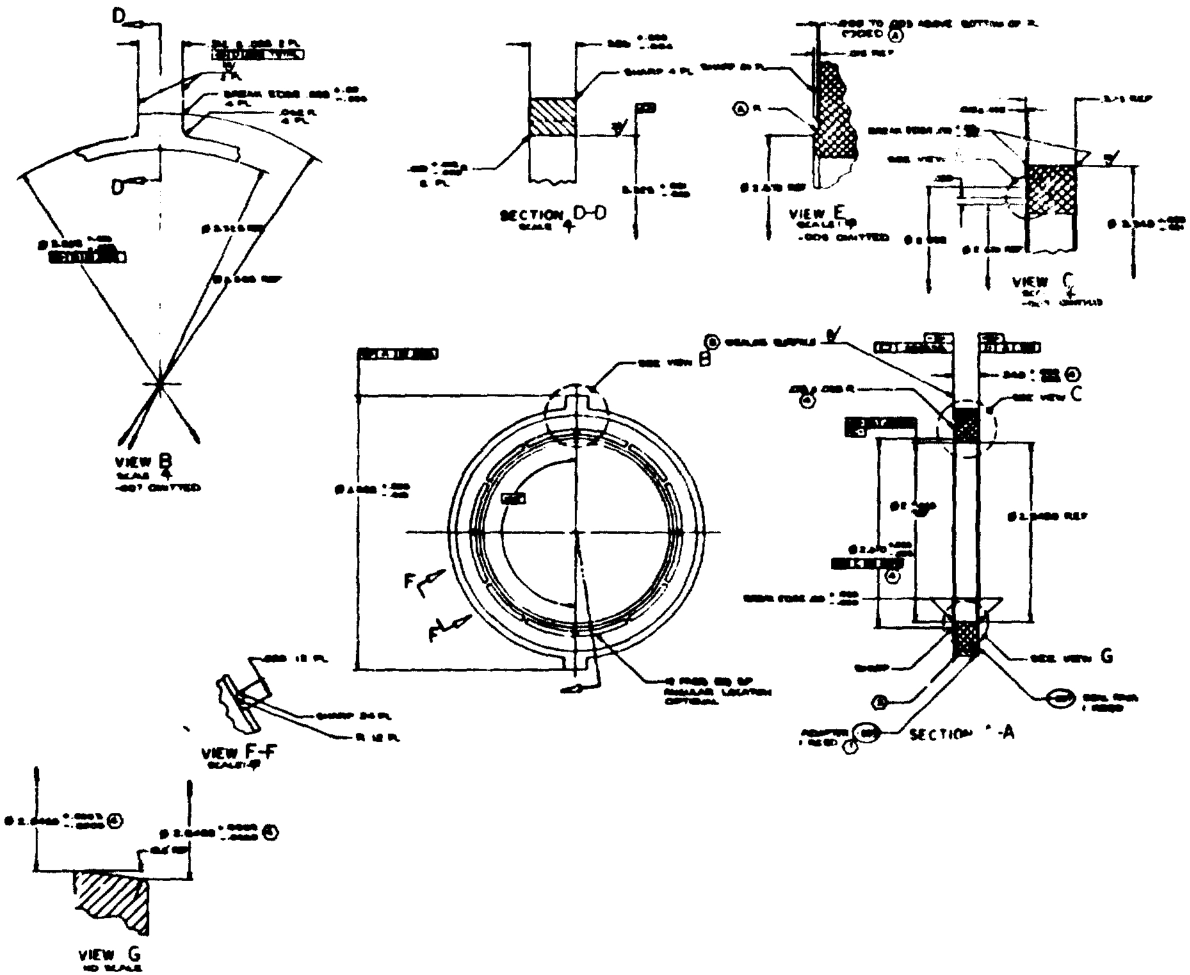

Figure 18. Tapered Bore Primary Seal Ring

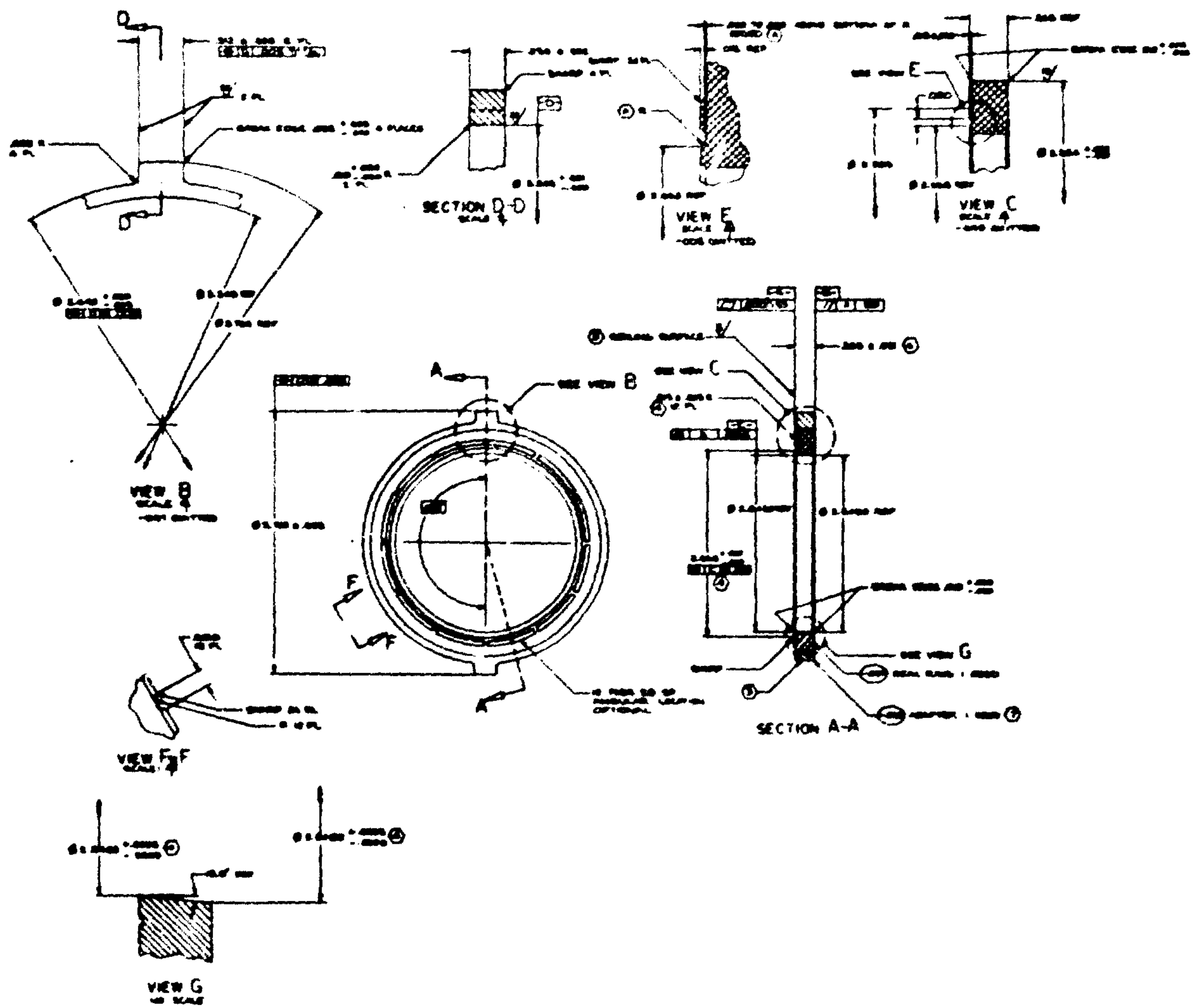

Figure 19. Tapered Bore Secondary Seal Ring

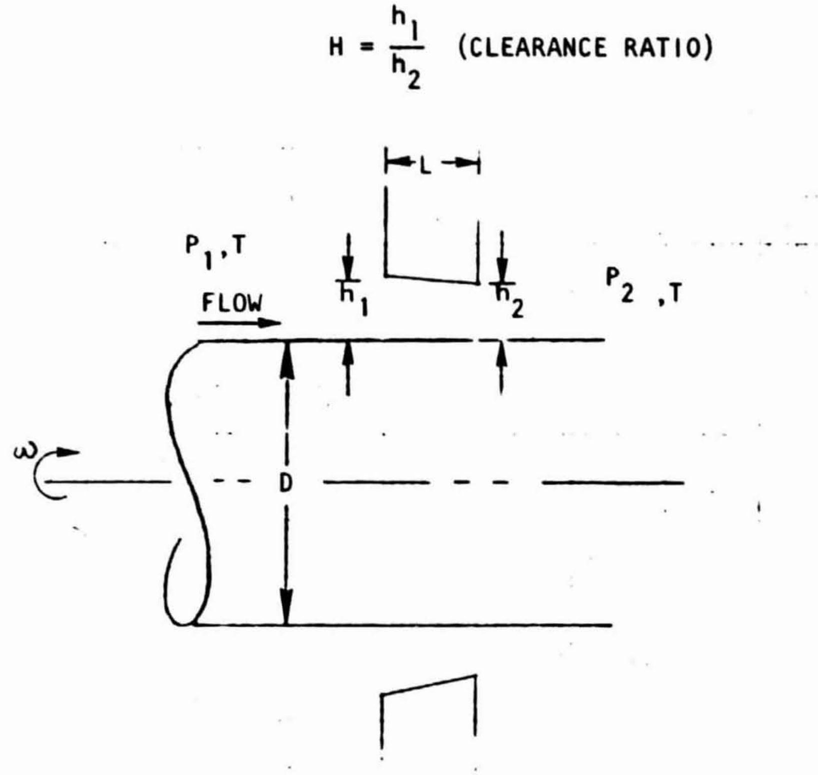

Figure 20. Tapered Bore Seal Nomenclature

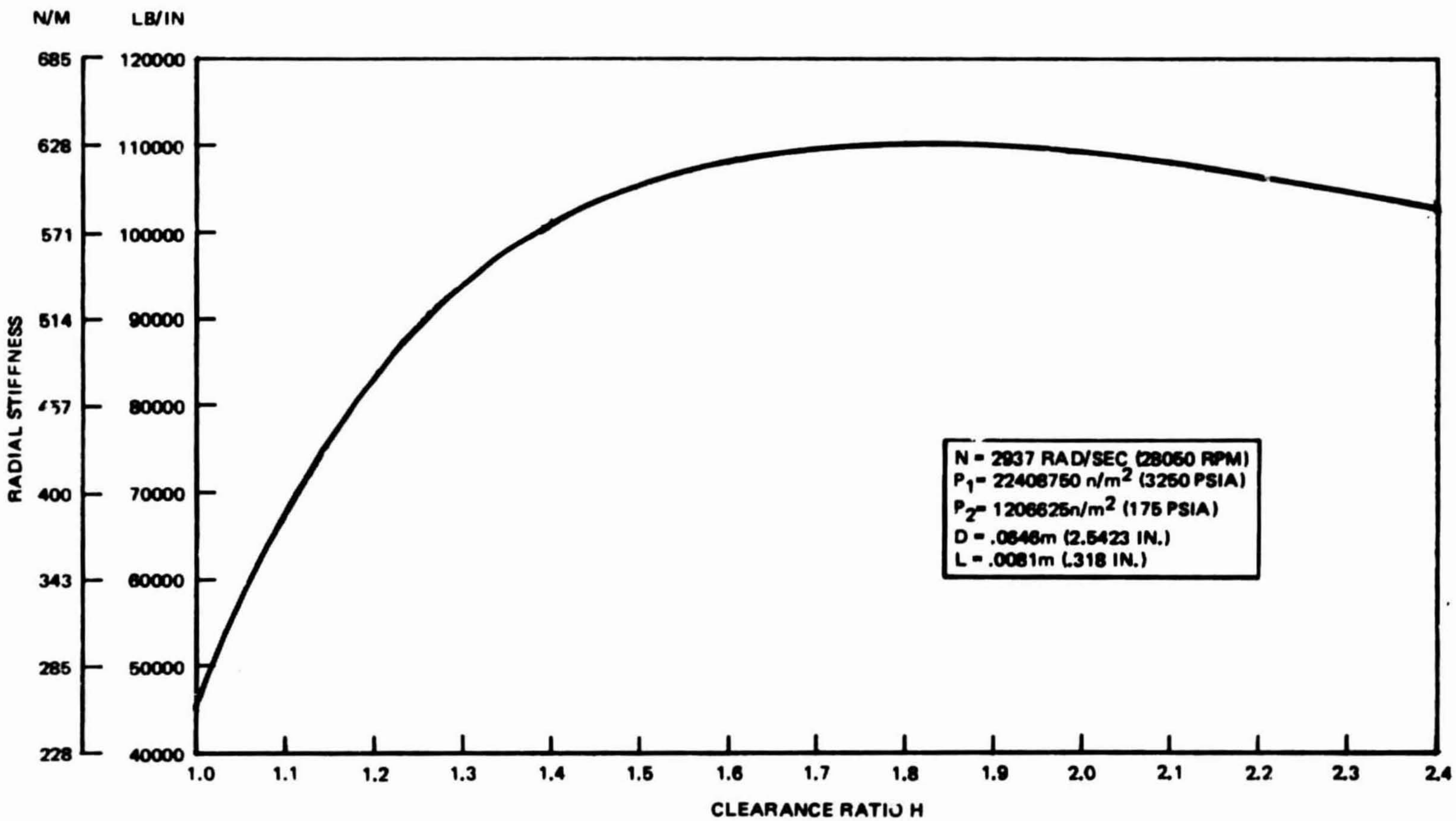

Figure 21. Tapered Bore Primary Seal Clearance Ratio vs Radial Stiffness

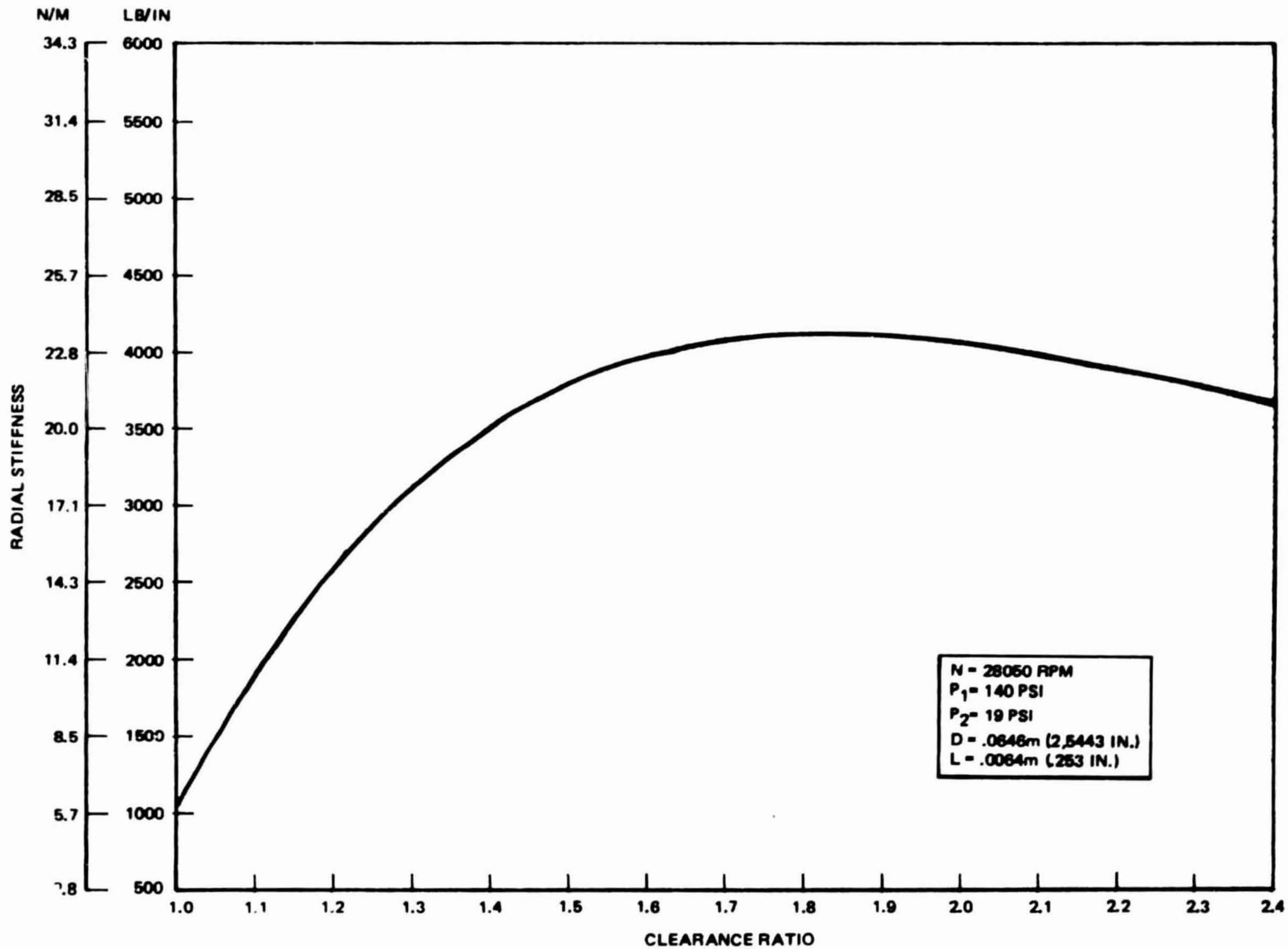

Figure 22. Tapered Bore Secondary Seal Clearance Ratio vs Radial Stiffness

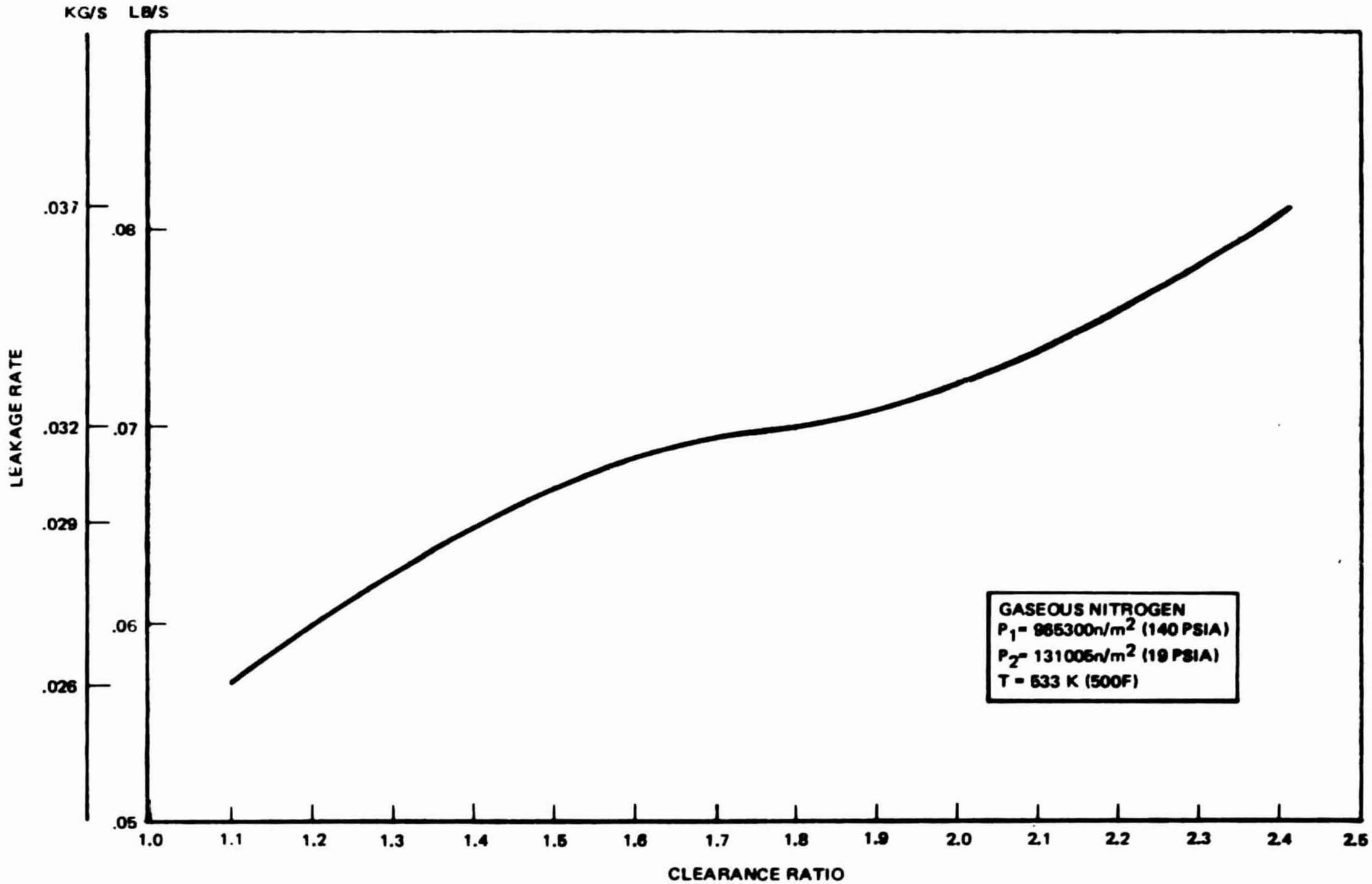

Figure 23. Tapered Bore Secondary Seal Leakage vs Clearance Ratio

is minus .000116 m (.0046 in.). The ambient installed diametral clearance on the small end is .000170 to .000185 m (.0067 to .0073 in.).

The seal ring nominal taper was established at .00005 m (.002 in.) diametral to provide a minimum of .000101 m (.004 in.) diametral operating clearance on the large end (high-pressure side). Nominal taper is based on the large end clearance being 1.8 times the small end operating clearance. The clearance ratio varies from 1.5 to 2.3. The seal clearances are summarized in Table 4.

The axial sealing surface of the seal rings was modified to add bearing support pads (Fig. 18). The pads share the axial load to reduce wear on the axial sealing dam.

A comparison of the hydrostatic centering force to the radial friction force indicates that the hydrostatic centering force exceeds the radial friction force by a significant margin; therefore, rubbing contact is not required to center the seal ring during steady-state operation. The tapered bore seal ring hydrostatic centering and radial friction forces are given below:

TAPERED BORE SEAL RING FORCES-N(LB)		
	PRIMARY	SECONDARY
HYDROSTATIC CENTERING	1659 (373)	60.0 (13.5)
RADIAL FRICTION	827 (186)	31.1 (7.0)

TABLE 4. TAPERED BORE SEAL DESIGN CLEARANCE SUMMARY

	PRIMARY*		SECONDARY*	
	MAX	MIN	MAX	MIN
INSTALLED				
INLET	.000312 (.0123)	.000297 (.0117)	.000236 (.0093)	.000220 (.0087)
OUTLET	.000261 (.0103)	.000246 (.0097)	.000185 (.0073)	.000170 (.0067)
OPERATING				
INLET	.000116 (.0046)	.000101 (.0040)	.000119 (.0047)	.000104 (.0041)
OUTLET	.000066 (.0026)	.000050 (.0020)	.000068 (.0027)	.000053 (.0021)
CLEARNACE RATIO (INLET/OUTLET)	2.3	1.54	2.24	1.52
*DIAMETRAL CLEARANCE-M (IN.)				

TEST FACILITY

Seal testing was accomplished at Rockwell International Rocketdyne Division, Engineering Development Laboratory rotatory test facility No. 1 (Fig. 24 and 25). Capabilities include 18.92m^3 (500 gal) pressurized gaseous nitrogen feed tank with a 51.09 m^3 (13,500 gal) liquid nitrogen storage. Maximum steady state flow was .0592 m^3/min (15.65gpm). A schematic of the seal test setup is shown on Figure 26.

Gaseous nitrogen was supplied to the tester from the feed tank by a pump producing an overall 41368543 n/m^2 (6000 psi) pressure system. All gaseous nitrogen flow was directed to the primary seal cavity common to both sets of seals. Inlet pressure was regulated at start by a manually controlled mechanical valve. Maximum pressure 24131650 n/m^2 (3500 psi) was achieved at start in under 10 seconds. The gaseous nitrogen temperature was achieved by feeding into a parallel flow heat exchanger regulated by a preset feedback system. Shaft speed was established by a 223800 KW (300 HP) D.C. electric dynamometer amplified by a 10-1 ratio gearbox. Acceleration and deceleration was manually controlled. The acceleration rate averaged approximately 314 rad/sec^2 (3000 rpm/sec).

A hot gaseous nitrogen purge was used before each acceleration test to insure proper system temperature during actual running. Purge gas was supplied through the regular plumbing, to the common primary seal cavity.

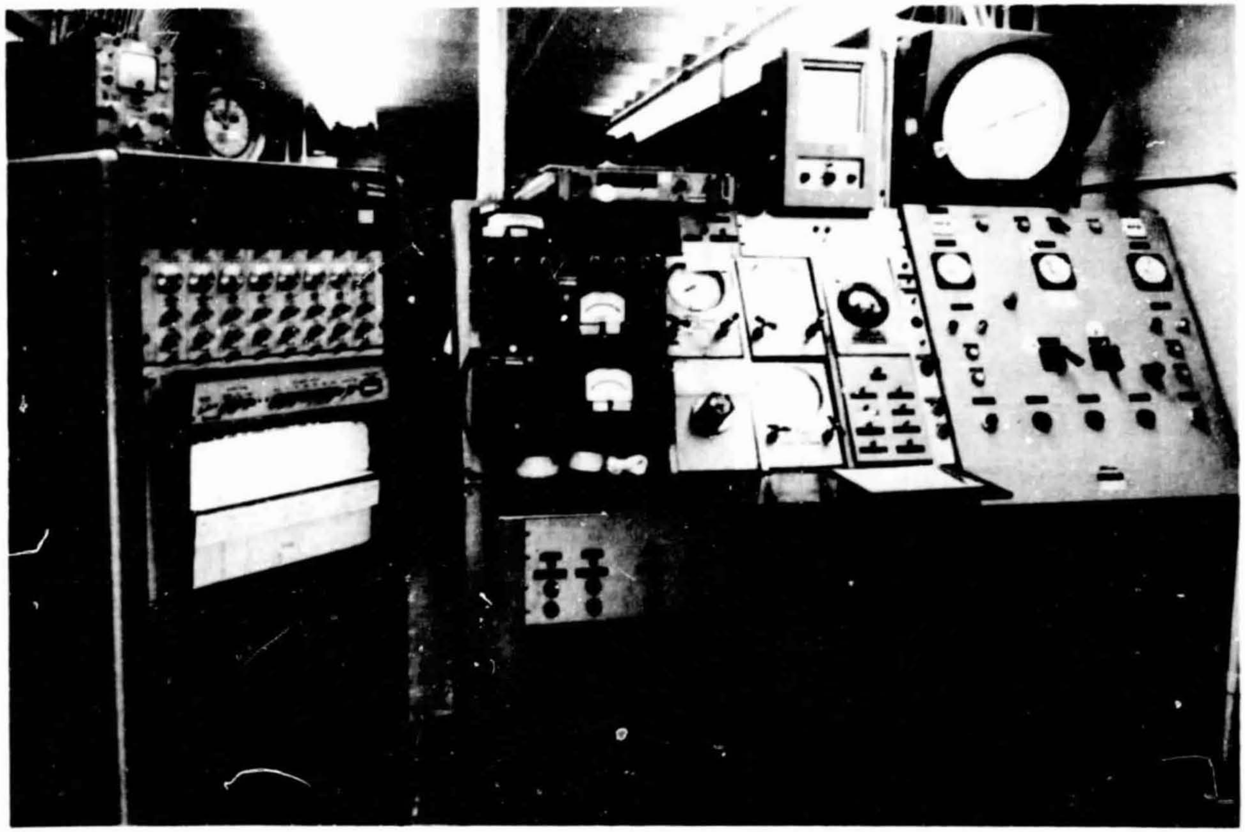

Figure 24. Rotatory Test Facility No. 1 Instrumentation Panel

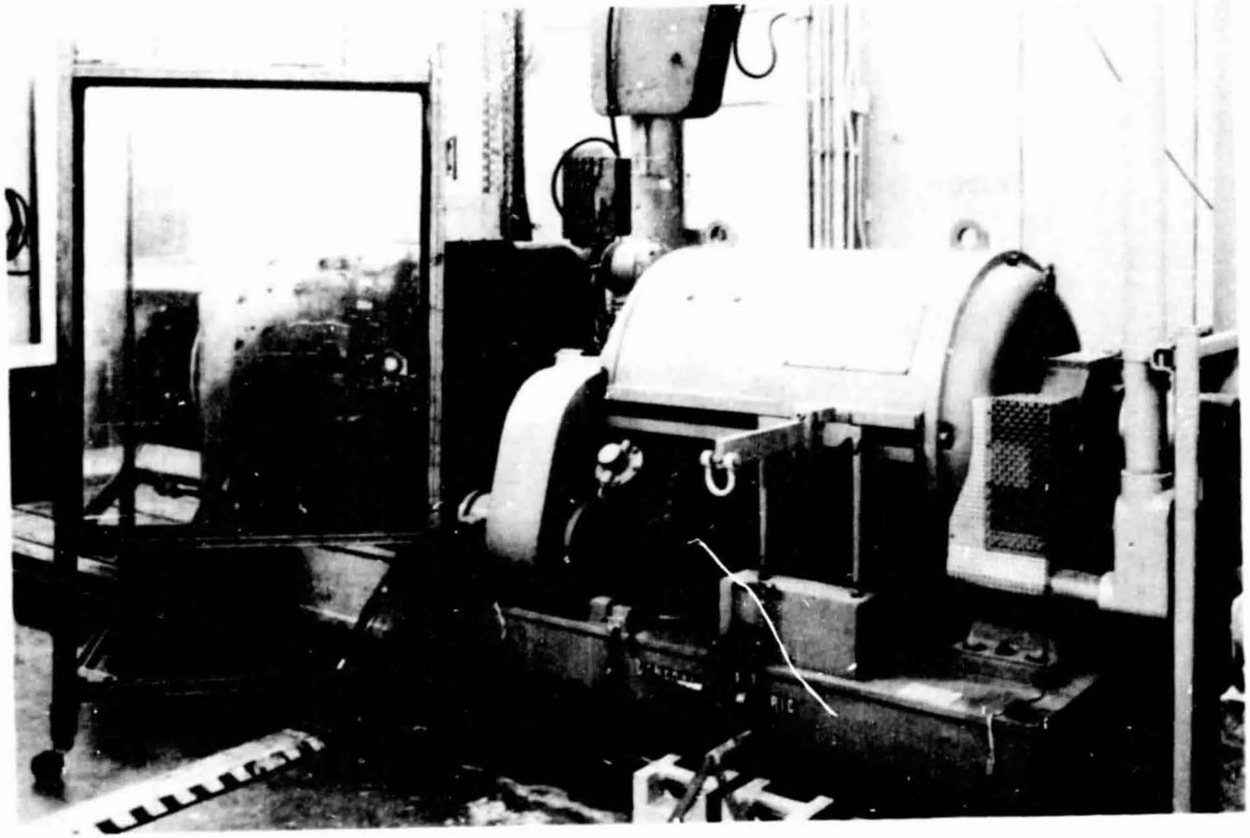

Figure 25. Rotatory Test Facility No. 1

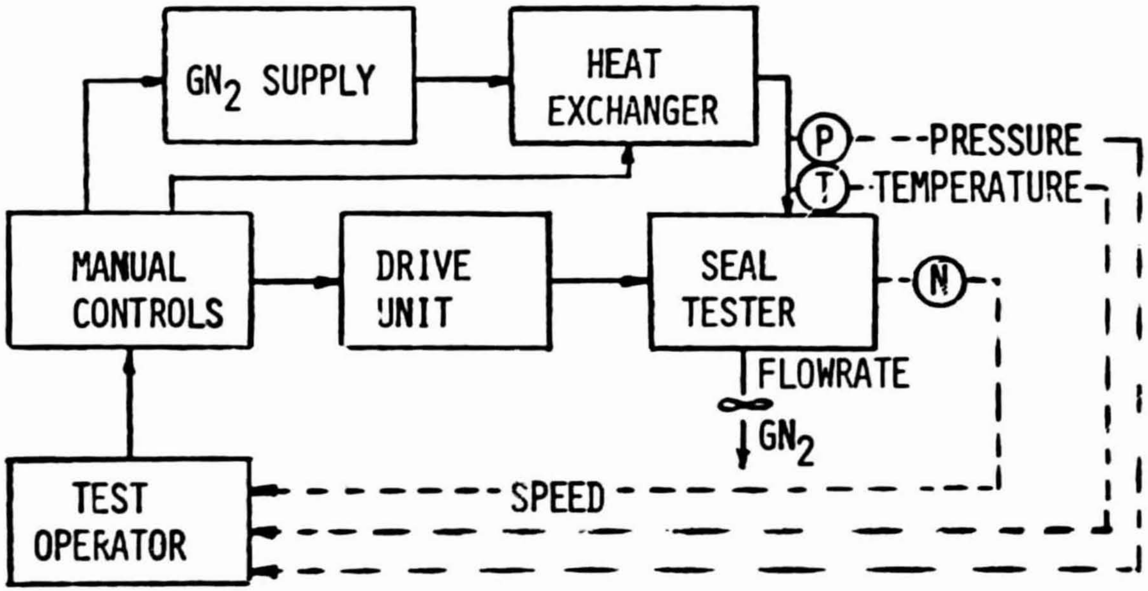

Figure 26. Turbine Seal Test Schematic

TEST HARDWARE

TESTER

The seal tester (Fig. 27) was designed and fabricated on a previous program for testing similar seals. The tester is designed to simulate the shaft dynamics of a turbopump. Simulated masses are located on the shaft to duplicate the turbopump critical speed and shaft deflection. Displacement transducers are located at each simulated mass. The actual turbopump bearings and bearing arrangements are used. The bearings are lubricated with oil and separated from the test seals with a face type oil seal.

Two test seals are installed back to back to provide a common high-pressure cavity for the hot gas. Atmospheric drains are provided between the primary and secondary rings and downstream of the secondary ring on each seal. The drains are equipped with instrumentation to measure pressure, temperature, and leakage. The drain area is sized to simulate the drains on a turbopump to duplicate the flow resistance.

SEALS

The Rayleigh step seal rings used in the initial phase of the test program are shown in Fig. 28 and 29. The tapered bore seal rings used in the final phase are shown in Fig. 30 and 31.

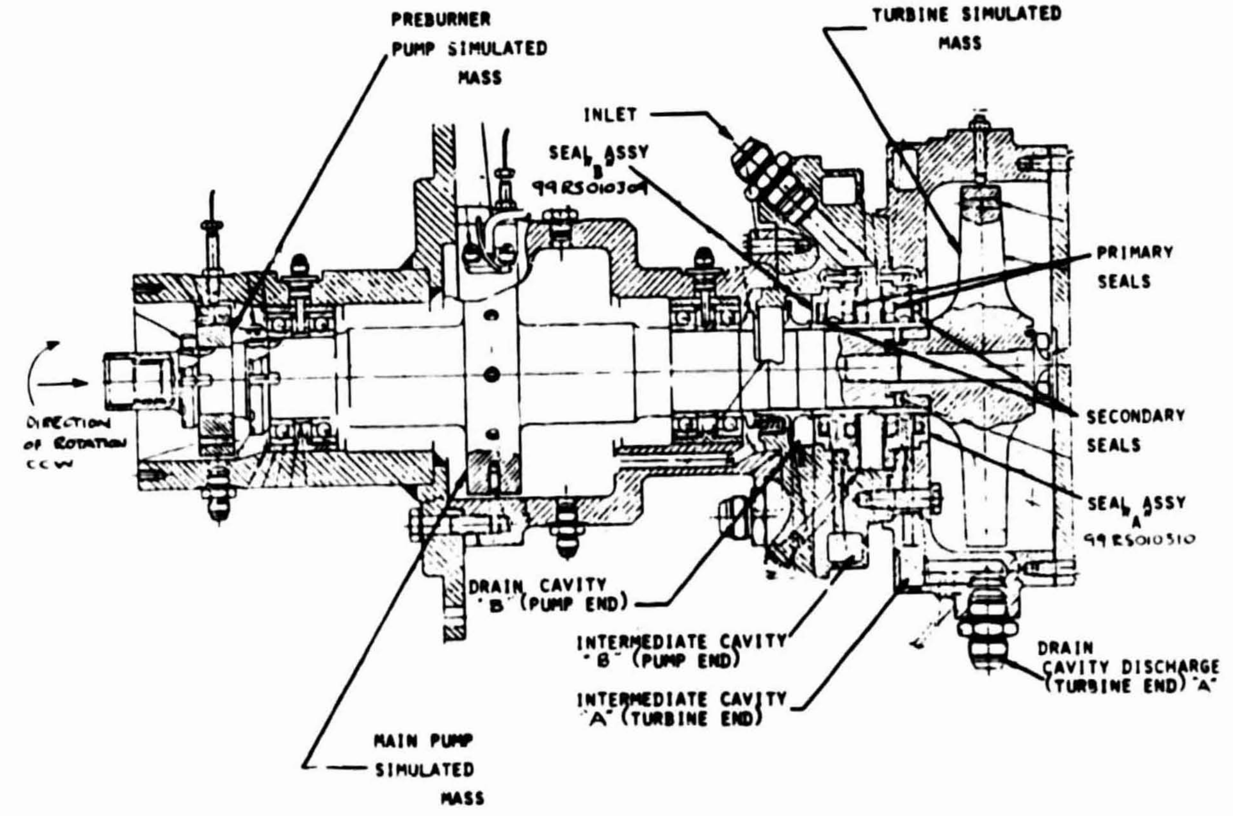

Figure 27. Turbine Seal Tester RS005100X

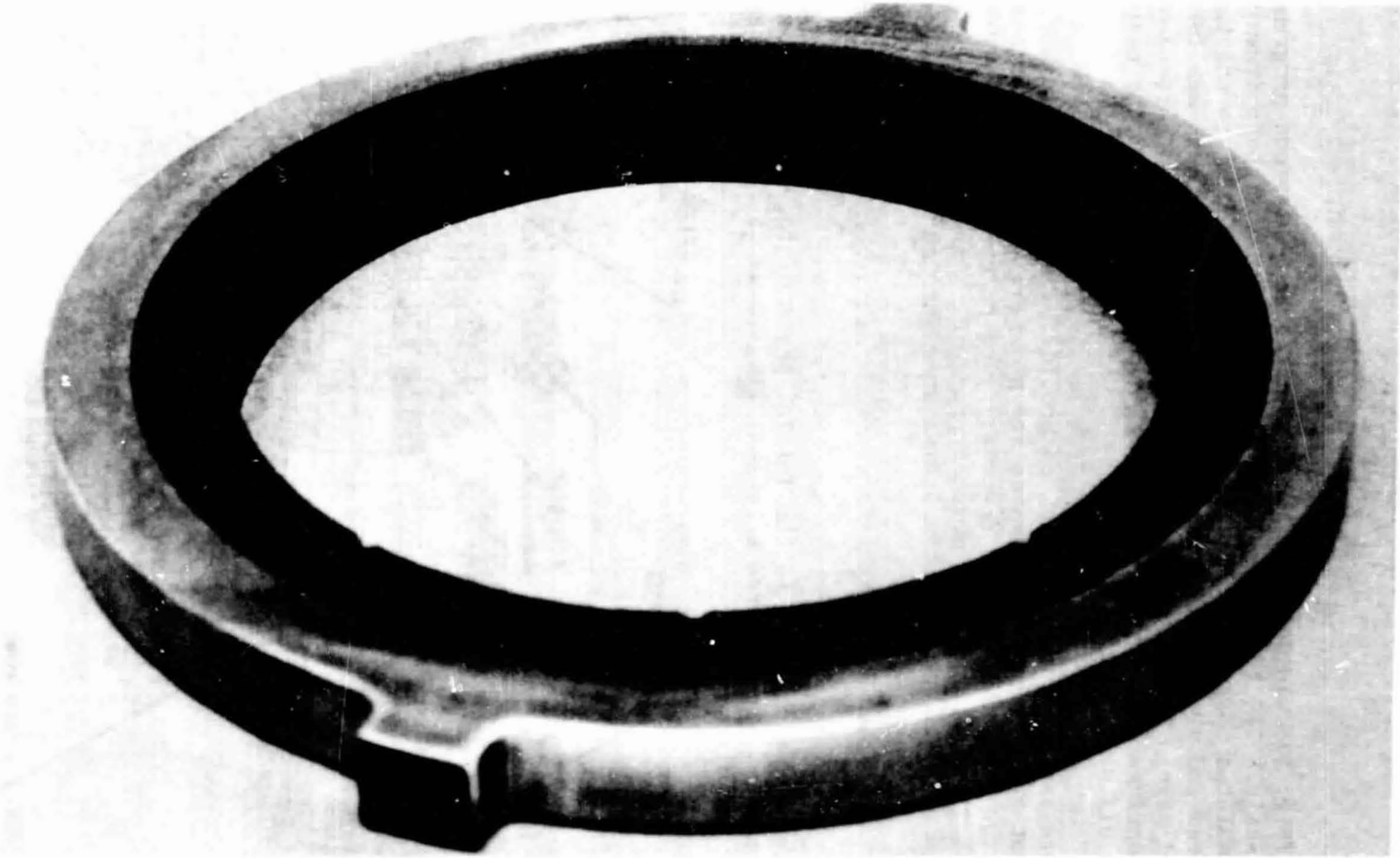

Figure 28. Rayleigh Step Primary Seal Ring (New)

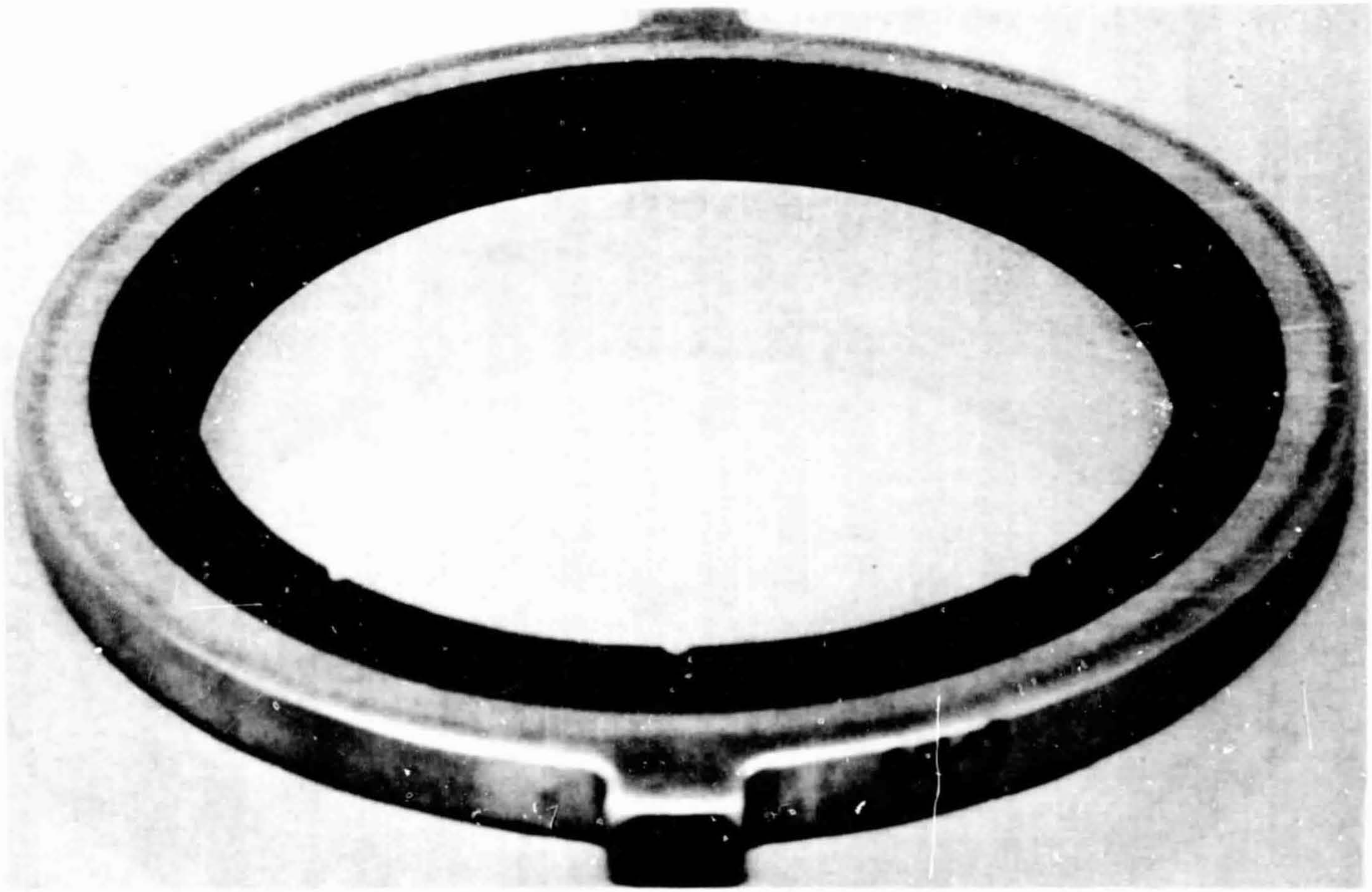

Figure 29. Rayleigh Step Secondary Seal Ring (New)

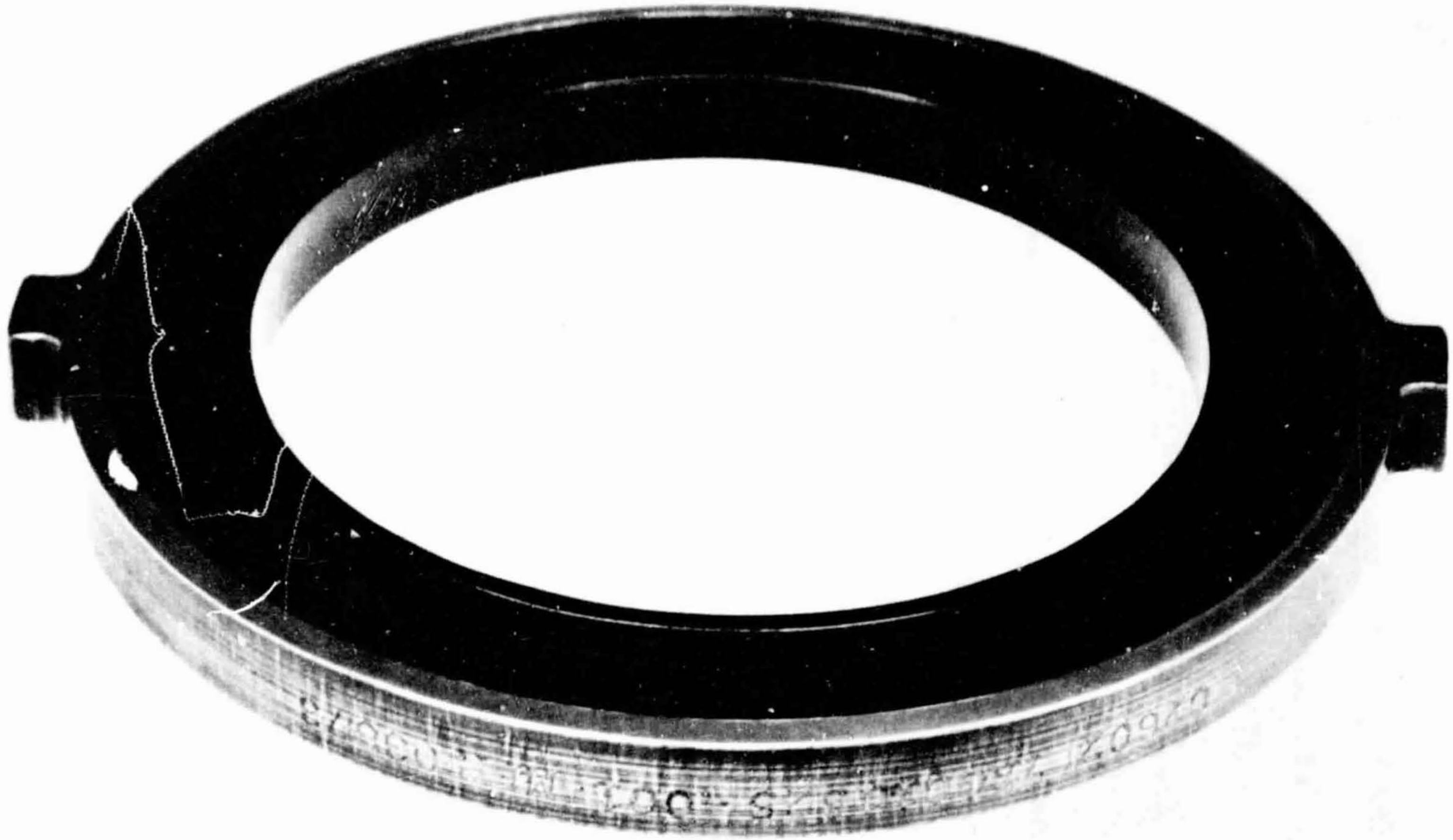

Figure 30. Tapered Bore Primary Seal Ring (New)

Figure 31. Tapered Bore Secondary Seal Ring (New)

TEST REQUIREMENTS

PROCEDURES

The test program consisted of preliminary checkout testing, hot gas nitrogen testing, and hot gaseous nitrogen acceleration testing. During checkout testing, one set of two seals was exposed to ambient nitrogen gas at progressively higher pressures in 3447378 n/m^2 (500 psi) increments from 1723689 to 25855339 n/m^2 (250 to 3750psia). Shaft speed was set at 33511 rad/sec (32000 rpm). Total test time for this phase was to be 12 starts for 30 minutes and four inspections.

Hot gaseous nitrogen testing consisted of exposing two sets of seals to 449 to 533K (350 to 500 F) nitrogen gas at eight pressure increments of 3447378 n/m^2 (500 psi) for 2.5 minutes each from 3447378 to 2585339 n/m^2 (500 to 3750 psi). Shaft speed to be steady at 3351 rad/sec (32,000 rpm). Total test time was to be 20 minutes with an inspection after every 10 minutes run time.

Hot gaseous nitrogen acceleration testing consisted of exposing two sets of two seals to hot gas for 7.5 hours (180 starts) each. Total test time would then be 360 starts for 15 hours. The shaft speed was ramped to 3351 rad/sec (32,000 rpm) in 10 seconds or less. The seal pressure was increased from 344737 to 24131650 n/m^2 (50 to 3500 psia). During the same period, the hot gas temperature was 533K (500 F) at start and gradually decayed to approximately 338K (150 F) at cutoff due to limited capacity of heat exchanger.

Inspection of the seals was scheduled for all new hardware and after four starts for 10 minutes and eight starts for 20 minutes during checkout testing. Inspection for acceleration testing was scheduled after every 60 starts for 150 minutes or when circumstances deemed inspection necessary.

Pretest procedures involved manually measuring the eccentricity of the rotating shaft and balancing accordingly using an adjustable counter weight on the end of the shaft. Displacement transducers were then placed on the shaft in lieu of the seals and the shaft eccentricity was monitored and measured at 314 rad/sec (3000 rpm) and 3036 rad/sec (29,000 rpm). A peak-to-peak maximum deflection of .0000635 m (0.0025 in.) was allowed. If this limit was exceeded, the counter weight would be repositioned and displacement measurements retaken. Upon installation, the shaft sleeve O.D. and the shaft sleeve extension beyond the end of the shaft was measured and recorded. Post test procedures involved an inspection of the seal hardware consisting of measuring dam heights, pad depths surface profile traces of the seal inner bore, the shaft sleeve surface and other pertinent data by surface profile traces and manual equipment.

INSTRUMENTATION

Instrumentation requirements, including redline limits, are listed in Table 5. Data were recorded continuously on direct inking graphic recorder charts. Location of the instrumentation taps is shown in Fig. 32.

TABLE 5. INSTRUMENTATION REQUIREMENTS

PRESSURES - n/m^2 (PSIA)	RANGE	REDLINE	RECORDER
P1 INLET	0-41368543(0-600)	29302718(4250) MAX	(1) (2)
P2 INTERMEDIATE CAVITY A	0-4136854(0-600)	8447378(500) MAX	(1)
P3 INTERMEDIATE CAVITY B	0-4136854(0-600)	8447378(500) MAX	(1)
P4 DRAIN CAVITY A	0-2068427(0-300)	—	(1)
P5 DRAIN CAVITY B	0-2068427(0-300)	689475(100) MAX	(1)
P6 NOZZLE IN PRI A	0-2068427(0-300)	—	(1) (2)
P7 NOZZLE IN PRI B	0-2068427(0-300)	—	(1) (2)
P8 NOZZLE IN SEC A	0-689475(0-100)	—	(1) (2)
P9 NOZZLE IN SEC B	0-689475(0-100)	—	(1) (2)
P10 2ND NOZZLE IN SEC B	0-1034213(0-150)	206842(300) MAX	(1)
TEMPERATURES - K(F)			
T1 INLET	294-533(70-500)	450 (350) MAX	(1)
T2 NOZZLE IN PRI A	294-533(70-500)	—	(1)
T3 NOZZLE IN PRI B	294-533(70-500)	—	(1)
T4 NOZZLE IN SEC A	294-533(70-500)	—	(1)
T5 NOZZLE IN SEC B	294-533(70-500)	—	(1)
DISPLACEMENT TRANSDUCERS m(IN.) T.I.R			
D1 TURBINE MASS POSITION 1	0-.00254(0-.01)	.0001524(.006) T.I.R.	(2) (3)
D2 TURBINE MASS POSITION 2	0-.00254(0-.01)	.0001524(.006) T.I.R.	(2) (3)
S1 SPEED RAD/SEC (RPM)	0-4188.8(0-40000)	3665.2(35000) MAX	(1) (2)
A1 ACCELEROMETER(GRMS)	0-10	10 MAX OR ABRUPT CHANGE	(2) (3)

(1) BRUSH RECORDER CONTINUOUS DURING TEST
(2) MAGNETIC TAPE DURING START AND STOP TRANSIENTS
(3) MONITORED ON OSCILLOSCOPE CONTINUOUS DURING TEST

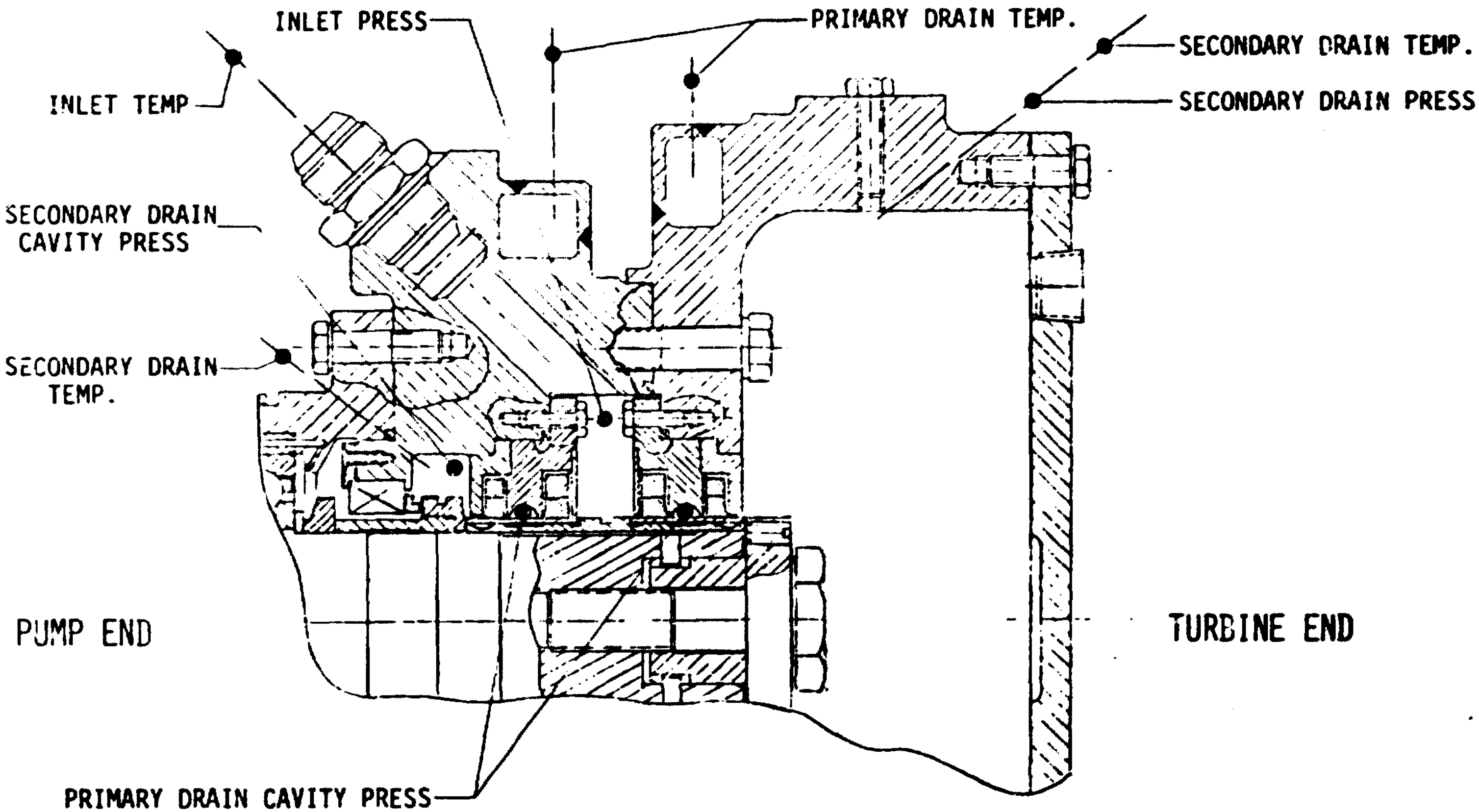

Figure 32. Instrumentation Location

Seal leakage measurements were recorded with a calibrated orifice differential pressure measurement. Seal cavity pressures and temperatures were obtained through the use of calibrated transducers and thermocouples. Two Bentlys displacement transducers, installed on the turbine end of the shaft in place of the seals, were used to check the shaft displacement at the test speed prior to acceleration testing. System vibration was monitored by an accelerometer positioned directly above the turbine end bearings. Displacement measurements were observed and recorded with an oscilloscope used in conjunction with a camera and recorded on high-frequency tape. These data were analyzed to ensure that shaft deflections were within operating limits.

Upon each installation of new hardware, a series of static (no rotation) pressure tests using existing seal instrumentation were performed. The data obtained were analyzed to determine if seal hardware and/or installation were faulty, as well as a basis for seal leakage data analysis.

TEST SCHEDULE I PRELIMINARY CHECKOUT

Preliminary checkout tests will be performed on four seals (2 of each part number) at room temperature with gaseous nitrogen. Test points, conditions, and inspection points per seal are as follows:

TEST POINT NUMBER	SHAFT SPEED, RAD/SEC (RPM)	SEAL PRESSURE, N/M^2 (PSIG)	DURATION, (MINUTES)
1	3351 (32000)	1723689 (250)	2.5
2	3351 (32000)	3447378 (500)	2.5
3	3351 (32000)	6894757 (1000)	2.5
INSPECT			
4	3351 (32000)	6894757 (1000)	2.5
5	3351 (32000)	10342135 (1500)	2.5
6	3351 (32000)	13789514 (2000)	2.5
INSPECT SEAL			
7	3351 (32000)	13789514 (2000)	2.5
8	3351 (32000)	17236893 (2500)	2.5
9	3351 (32000)	20684271 (3000)	2.5
INSPECT SEAL			
10	3351 (32000)	20684271 (3000)	2.5
11	3351 (32000)	24131650 (3500)	2.5
12	3351 (32000)	25855339 (3750)	2.5
INSPECT SEAL			

TEST SCHEDULE II HOT GASEOUS NITROGEN TESTING

Hot-gas test runs will be performed on four seals (2 of each part number) using gaseous nitrogen at 533K (500 F). Test points, conditions, and inspection points per seal are as follows:

TEST POINT NUMBER	SHAFT SPEED RAD/SEC (RPM)	GAS TEMPERATURE K (F)	SEAL PRESSURE N/M^2 (PSIG)	DURATION MINUTES
1	3351 (32000)	533 (500)	3447378 (500)	2.5
2	3351 (32000)	533 (500)	6894757 (1000)	2.5
3	3351 (32000)	533 (500)	10342135 (1500)	2.5
4	3351 (32000)	533 (500)	13789514 (2000)	2.5
INSPECT SEAL				
5	3351 (32000)	533 (500)	17236893 (2500)	2.5
6	3351 (32000)	533 (500)	20684271 (3000)	2.5
7	3351 (32000)	533 (500)	24131650 (3500)	2.5
8	3351 (32000)	533 (500)	25855339 (3750)	2.5
INSPECT SEAL				

TEST SCHEDULE III HOT GASEOUS NITROGEN ACCELERATION TESTING

Hot-gas acceleration test runs will be performed on four seals (2 of each part number) using gaseous nitrogen 533K (500 F). The following test conditions will be maintained until a total of 240 starts have been accumulated with a total test time of 7.5 hours per seal. The shaft speed and seal pressure shall be ramped from zero to the specified test condition in 10 seconds or less.

SHAFT SPEED RAD/SEC (RPM)	SEAL PRESSURE N/M^2 (PSIG)	GAS TEMPERATURE K (F)	DURATION (MINUTES)
3351 (0 to 32,000)	24131650 (0 to 3500)	533 (500)	2.5

Inspect seal at 2.5 hour intervals (four inspections required).

RESULTS AND DISCUSSION

TEST SUMMARY

The test summary is given in Table 6.

HARDWARE SUMMARY

The hardware summary is given in Table 7.

INSPECTION SUMMARY

The Rayleigh step seal inspection summary is given in Table 8 for U.S. Customary units and Table 9 for SL units.

The tapered bore seal inspection summary is given in Table 10 for U.S. Customary units and Table 11 for SI units.

DATA SUMMARY

The test data summary is given in Table 12 for English units and Table 13 for SI units.

TESTER SHAFT DEFLECTION CHECKOUT TESTING

The initial tester shaft deflection tests measuring the runout at the turbine seal location indicated excessive deflection. The displacement transducer at the seal location did not record; however, the transducer at the turbine wheel location indicated .0004318 m (.017 in.) peak to peak deflection. Investigation indicated that the most probable cause of the excessive deflection was the tooling sleeve used with the displacement transducers. The sleeve has a loose fit on the shaft which could allow the sleeve to be slightly eccentric. The resulting unbalance of the rotating assembly would cause excessive deflection.

The tooling sleeve was replaced with an actual test sleeve which was reworked to add a calibration notch for the displacement transducer. The test sleeve has a press fit to the shaft to maintain concentricity. Smaller displacement transducers were used to allow the same sleeve to be utilized for seal testing. The tester was rebuilt and the shaft deflection testing with the actual test sleeve prior to installing the test seals was completed. The sleeve runout was .0000254 m (.001 in.) peak to peak at 31.4 rad/sec (300 rpm). The final sleeve runout after balance was .0000254 m (.001 in.) peak to peak at 733 rad/sec (7000 rpm) and .0000361 m (.0015 in.) peak to peak at 3193 rad/sec (30500 rpm). The final wheel runout was .0000762 m (.003 in.) peak to peak at 3193 rad/sec (30500 rpm).

The wheel runout will be used as an indication of the seal sleeve runout during the seal testing. The ratio of the wheel runout to the sleeve runout is 2 to 1. The sleeve runout during acceleration through the critical speed transient was .0001016 to .0001524 m (.004 to .006 in.) peak to peak for a period of

TABLE 6. SEAL TEST SUMMARY

BUILD NO.	TESTS	STARTS	TIME, MINUTES	OBJECTIVE	SEAL HARDWARE			
					PUMP END	TURBINE END	MATING RING SLEEVE	
1	001-003	3	7.5	PRELIMINARY CHECKOUT AMBIENT GN_2 3351.04 RAD/SEC (32,000 RPM), 1723689.3, 3447378.6, 6894757.2 N/m^2 (250, 500, 1000 PSIG)	RAYLEIGH STEP, NEW, PRIMARY P/N 99RS010302 S/N 02 SECONDARY P/N 99RS010304 S/N 01	RAYLEIGH STEP, NEW, PRIMARY P/N 99RS010303 S/N 01 SECONDARY P/N 99RS010305 S/N 01	NEW - P/N RS0050928 S/N 01	SCHEDULED INSPECTION; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION FAIR; LIFT PADS WORN OFF ON TURBINE END PRIMARY AND PUMP END SECONDARY SEAL RINGS; TURBINE END PRIMARY INSTALLED BACKWARDS
2	004-006	3	6.75	PRELIMINARY CHECKOUT AMBIENT GN_2 3351.04 RAD/SEC (32,000 RPM), 6894757.2, 10342135.8, 13789514.4 N/m^2 (1000, 1500, 2000 PSIG)	RAYLEIGH STEP, SAME AS BUILD 1	RAYLEIGH STEP, SAME AS BUILD 1	SAME AS BUILD 1	TEST 006 CUT DUE TO SUDDEN SPEED DROP; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION FAIR; SLIGHT ADDITIONAL WEAR
3	007-009	3	7.5	PRELIMINARY CHECKOUT AMBIENT GN_2 3351.04 RAD/SEC (32,000 RPM); 13789514.4, 17236893, 20684271.6 N/m^2 (2000, 2500, 3000 PSIG)	RAYLEIGH STEP, SAME AS BUILD 2	RAYLEIGH STEP, SAME AS BUILD 2	SAME AS BUILD 2	SCHEDULED INSPECTION; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION FAIR; LIFT PADS WORN OFF ON TURBINE END PRIMARY AND SECONDARY AND PUMP END SECONDARY SEAL RINGS
4	010-012	3	7.5	PRELIMINARY CHECKOUT AMBIENT GN_2 3351.04 RAD/SEC (32,000 RPM), 18615844.44, 20684271.6, [illegible] N/m^2 (2700, 3000, 3200 PSIG)	RAYLEIGH STEP, SAME AS BUILD 3	RAYLEIGH STEP, SAME AS BUILD 3	SAME AS BUILD 3	COMPLETED PRELIMINARY CHECKOUT; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION POOR; LIFT PADS WORN OFF ON ALL SEAL RINGS; SOME EROSION ON LEADING EDGE OF SEALING DAMS, EXCESSIVE SHAFT RADIAL DEFLECTION NOTICED
5	013-016	4	10	HOT GN_2 TESTING 533.15 K (500 F) GN_2, 3351.04 RAD/SEC (32,000 RPM), 3447378.6, 6894757.2, 10342135.8, 13789514.4 N/m^2 (500, 1000, 1500, 2000 PSIG)	RAYLEIGH STEP, NEW, PRIMARY S/N 04 SECONDARY S/N 04	RAYLEIGH STEP, NEW, PRIMARY S/N 06 SECONDARY S/N 05	NEW - S/N 02	SCHEDULED INSPECTION; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION GOOD/FAIR; LIFT PADS WORN OFF ON TURBINE END SECONDARY SEAL, OTHER WEAR NEGLIGIBLE; EXCESSIVE SHAFT RADIAL DISPLACEMENT NOTICED
6	017-020	4	10	HOT GN_2 TESTING 533.15 K (500 F) GN_2 3351.04 RAD/SEC (32,000 RPM), 17236893, 20684271.6, 24131650.2, 26027708.42 N/m^2 (2500, 3000, 3500, 3775 PSIG)	RAYLEIGH STEP, SAME AS BUILD 5	RAYLEIGH STEP, SAME AS BUILD 5	SAME AS BUILD 5	COMPLETED HOT GN_2 TESTING; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION GOOD/FAIR; NO SIGNIFICANT ADDITIONAL WEAR; UPSTREAM EDGE OF TURBINE END PRIMARY RING SEALING DAM ERODED DUE TO HIGH VELOCITY GAS LEAKAGE; ASSEMBLY AND BALANCE PROCEDURES REVISED TO ELIMINATE EXCESSIVE SHAFT RADIAL DISPLACEMENT
7	021-029	9	29.15	HOT GN_2 ACCELERATION TESTING, 533.15 K (500 F) GN_2; 3351.04 RAD/SEC (32,000 RPM), 25510801.64 N/m^2 (3700 PSIG)	RAYLEIGH STEP, NEW, PRIMARY S/N 05 SECONDARY: S/N 05	RAYLEIGH STEP, PRIMARY S/N 05 SECONDARY S/N 04	NEW - S/N 03	INSPECTION DUE TO HIGH LEAKAGE AND DRAIN CAVITY PRESSURES; SEAL CONDITION FAIR; LIFT PADS WORN AWAY ON TURBINE END SECONDARY SEAL RING; TURBINE END PRIMARY SEAL RING SEALING DAM ERODED AXIALLY AND CHIPPED ON UPSTREAM EDGE
8	030-080	51	121	HOT GN_2 ACCELERATION TESTING 533.15 K (500 F) GN_2, 3351.04 RAD/SEC (32,000 RPM), 25510801.64 N/m^2 (3700 PSIG)	RAYLEIGH STEP, SAME AS BUILD 7	RAYLEIGH STEP, SAME AS BUILD 7	SAME AS BUILD 7	SCHEDULED INSPECTION; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION FAIR; SOME ADDITIONAL LIFT PAD WEAR; CONTINUED EROSION OF TURBINE END PRIMARY SEAL RING SEALING DAM
9	081-107	27	71.97	HOT GN_2 ACCELERATION TESTING, 533.15 K (500 F) GN_2; 3351.04 RAD/SEC (32,000 RPM), 25510801.64 N/m^2 (32,000 RPM)	RAYLEIGH STEP, SAME AS BUILD 8	RAYLEIGH STEP, SAME AS BUILD 8	SAME AS BUILD 8	INSPECTION DUE TO SUDDEN INCREASE IN ALL DRAIN CAVITY PRESSURES; TURBINE END PRIMARY SEAL RING SEALING DAM FRAGMENTED AROUND CIRCUMFERENCE; LIFT PADS WORN OFF ON TURBINE END SEALS; RAYLEIGHT STEP TESTING DISCONTINUED
10	108-111	4	10	HOT GN_2 TESTING 533.15 K (500 F) GN_2, 3036.88 RAD/SEC (29,000 RPM); 3447378.6, 6894751.2, 10342135.8, 13789514.4 N/m^2 (500, 1000, 1500, 2000 PSIG)	TAPERED BORE, NEW, PRIMARY: P/N 7R0011525 S/N 047906 SECONDARY: P/N 7R0011526 S/N 047902	TAPERED BORE, NEW, PRIMARY: P/N 7R0011525 S/N 047901 SECONDARY: P/N 7R0011526 S/N 047901	NEW - P/N RS0050928-005 S/N 04	COMPLETED HOT GN_2 TESTING; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION GOOD

TABLE 6. (Concluded)

BUILD NO.	TESTS	STARTS	TIME, MINUTES	OBJECTIVE	SEAL HARDWARE: PUMP END	SEAL HARDWARE: TURBINE END	SEAL HARDWARE: MATING RING SLEEVE	
11	112-115	4	11.1	HOT GH_2 TESTING, 533.15 K (500 F) GH_2, 3036.88 RAD/SEC (29,000 RPM), 1723689.3, 20684271.6, 22407960.9, 24131650.2 N/m² (2500, 3000, 3250, 3500 PSIG)	TAPERED BORE, SAME AS BUILD 10	TAPERED BORE, SAME AS BUILD 10	SAME AS BUILD 10	COMPLETED HOT GH_2 TESTING; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION GOOD WITH NEGLIGIBLE WEAR
12	116-158	43	107.5	HOT GH_2 ACCELERATION TESTING, 533.15 K (500 F) GH_2, 3036.88 RAD/SEC (29,000 RPM), 24131650.2 N/m² (3500 PSIG)	TAPERED BORE, SAME AS BUILD 11	TAPERED BORE, SAME AS BUILD 11	SAME AS BUILD 11	BEARING FAILURE, SEAL PERFORMANCE SATISFACTORY PRIOR TO FAILURE, SEAL CONDITION GOOD WITH NEGLIGIBLE WEAR EXCEPT FOR TURBINE END SECONDARY SEAL, WHICH WAS WORN; WEAR MAY BE RESULT OF BEARING FAILURE
13	159-218	60	150	HOT GH_2 ACCELERATION TESTING, 533.15 K (500 F) GH_2, 3036.88 RAD/SEC (29,000 RPM), 24131650.2 N/m² (3500 PSIG)	TAPERED BORE, NEW PRIMARY S/N 047909 SECONDARY S/N 047909	TAPERED BORE, NEW, PRIMARY S/N 047907 SECONDARY S/N 047907	NEW - S/N 01	SCHEDULED INSPECTION; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION GOOD WITH NEGLIGIBLE WEAR EXCEPT FOR SOME WEAR ON TURBINE END SECONDARY SEAL LIFT PAD
14	219-278	60	150	HOT GH_2 ACCELERATION TESTING, 533.15 K (500 F) GH_2, 3036.88 RAD/SEC (29,000 RPM), 24131650.2 N/m² (3500 PSIG)	TAPERED BORE, SAME AS BUILD 13	TAPERED BORE, SAME AS 13	SAME AS BUILD 13	SCHEDULED INSPECTION; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION GOOD EXCEPT TURBINE END SECONDARY SEAL LIFT PAD WORN OFF AT ONE LOCATION
15	279-297	19	47.5	HOT GH_2 ACCELERATION TESTING, 533.15 K (500 F) GH_2, 3036.88 RAD/SEC (29,000 RPM), 24131650.2 N/m² (3500 PSIG)	TAPERED BORE, SAME AS BUILD 14	TAPERED BORE, SAME AS BUILD 14	SAME AS BUILD 14	COMPLETED ACCELERATION TESTING ON FIRST SET OF SEALS; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION GOOD EXCEPT TURBINE END SECONDARY SEAL LIFT PAD WORN OFF; WEAR MAY BE RESULT OF SHAFT DEFLECTIONS AT TURBINE END
16	298-357	60	150	PRETEST STATIC LEAKAGE CHECKOUT AND HOT GH_2 ACCELERATION TESTING, 533.15 K (500 F) GH_2, 3036.88 RAD/SEC (29,000 RPM), 24131650.2 N/m² (3500 PSIG)	TAPERED BORE, NEW, PRIMARY S/N 05 SECONDARY S/N 05	TAPERED BORE, NEW, PRIMARY S/N 08 SECONDARY S/N 08	NEW - S/N 02	SCHEDULED INSPECTION; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION GOOD EXCEPT FOR SOME WEAR ON THE TURBINE END SECONDARY SEAL RINGS
17	358-417	60	150	HOT GH_2 ACCELERATION TESTING: 533.15 K (500 F) GH_2, 3036.88 RAD/SEC (29,000 RPM), 24131650.2 N/m² (3500 PSIG)	TAPERED BORE, SAME AS BUILD 16	TAPERED BORE, SAME AS BUILD 16	SAME AS BUILD 16	SCHEDULED INSPECTION; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION GOOD ON PRIMARY SEALS, FAIR ON SECONDARY SEALS
18	418-421	4	10	HOT GH_2 ACCELERATION TESTING: 533.15 K (500 F) GH_2; 3036.88 RAD/SEC (29,000 RPM), 24131650.2 N/m² (3500 PSIG)	TAPERED BORE, SAME AS BUILD 17	TAPERED BORE, SAME AS BUILD 17	SAME AS BUILD 17	FACILITY LH_2 PUMP PROBLEM; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION GOOD ON PRIMARY SEALS, FAIR ON SECONDARY SEALS
19	422-436	15	37.5	HOT GH_2 ACCELERATION TESTING: 533.15 K (500 F) GH_2; 3036.88 RAD/SEC (29,000 RPM) 24131650.2 N/m² (3500 PSIG)	TAPERED BORE, SAME AS BUILD 18	TAPERED BORE, SAME AS BUILD 18	SAME AS BUILD 18	FACILITY LH_2 PUMP PROBLEM; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION GOOD ON PRIMARY SEALS, FAIR ON SECONDARY SEALS
20	437-477	41	102.5	HOT GH_2 ACCELERATION TESTING: 533.15 K (500 F) GH_2; 3036.88 RAD/SEC (29,000 RPM) 24131650.2 N/m² (3500 PSIG)	TAPERED BORE, SAME AS BUILD 19	TAPERED BORE, SAME AS BUILD 19	SAME AS BUILD 19	COMPLETED TESTING; SEAL PERFORMANCE SATISFACTORY; SEAL CONDITION GOOD ON PRIMARY SEALS, FAIR ON SECONDARY SEALS

TABLE 7. (Continued)

BUILD NO.	STARTS	TIME MIN.	PUMP END SEAL PRIMARY PN SN	PUMP END SEAL SECONDARY PN SN	TURBINE END SEAL PRIMARY PN SN	TURBINE END SEAL SECONDARY PN SN	MATING RING PN SN	HARDWARE CONDITION PRETEST	HARDWARE CONDITION POST TEST
6	4	10	99RS010302 04	99RS010304 04	99RS010303 06	99RS010305 05	RS005092X 02	SAME AS BUILD 5	PUMP END PRIMARY SEAL RING IN GOOD CONDITION WITH NEGLIGIBLE WEAR; TURBINE END PRIMARY IN GOOD CONDITION EXCEPT FOR EROSION OF THE SEALING DAM UPSTREAM EDGE; NO ADDITIONAL WEAR ON OTHER SEAL RINGS; SHAFT SLEEVE HAD A CARBON DEPOSIT IN SEAL RING AREA, BUT NEGLIGIBLE WEAR
7	9	29.15	99RS010302 05	99RS010304 05	99RS010303 05	99RS010305 04	RS005092X 03	NEW	PUMP END PRIMARY SEAL RING IN GOOD CONDITION WITH NEGLIGIBLE WEAR; TURBINE END PRIMARY SEALING DAM WAS CHIPPED AND WORN .000508 TO .000762 M (.020 TO .030 IN.); TURBINE END SECONDARY LIFT PADS WORN AWAY AND CARBON BORE WORN .00013462 M (.0053 IN.) TOTAL; PUMP END SECONDARY LIFT PADS WORN .00001016 M (.0004 IN.) TOTAL; SHAFT SLEEVE IN GOOD CONDITION WITH NEGLIGIBLE WEAR
8	51	121	-	-	-	-	-	SAME AS BUILD 7	PUMP END PRIMARY SEAL RING IN GOOD CONDITION WITH NEGLIGIBLE WEAR; TURBINE END PRIMARY SEALING DAM CHIPPED AND WORN, AND LIFT PADS WORN AWAY IN ONE PLACE; TURBINE END SECONDARY LIFT PADS WORN AWAY, AND CARBON BORE WORN .00013462 M (.0053 IN.) TOTAL; PUMP END SECONDARY LIFT PADS WORN .00001016 M .004 IN.) TOTAL; SHAFT SLEEVE IN GOOD CONDITION WITH NEGLIGIBLE WEAR
9	27	71.97	-	-	-	-	-	SAME AS BUILD 8	TURBINE END PRIMARY SEALING DAM FRAGMENTED; CARBON BORE WORN .00398780 M (.0157 IN.) TOTAL AND LIFT PADS WORN AWAY; TURBINE END SECONDARY SEAL AND PUMP END SECONDARY SEAL LIFT PADS WORN AWAY IN TWO PLACES AND CARBON BORE WORN .00012192 M (.0048 IN.) TOTAL; SHAFT SLEEVE TURBINE END PRIMARY SURFACE WORN .0001651 TO .0002413 M (.0065 TO .0095 IN.)

TABLE 7. (Continued)

BUILD NO.	STARTS	TIME MIN.	PUMP END SEAL PRIMARY PN SN	PUMP END SEAL SECONDARY PN SN	TURBINE END SEAL PRIMARY PN SN	TURBINE END SEAL SECONDARY PN SN	MATING RING PN SN	HARDWARE CONDITION PRETEST	HARDWARE CONDITION POST TEST
10	4	10.0	7R0011525 047906	7R0011526 047902	7R0011525 047901	7R0011526 047901	RS005092X-005 4	NEW	SEAL RING AND SLEEVE IN GOOD CONDITION WITH NEGLIGIBLE WEAR, EXCEPT TURBINE END SECONDARY PAD WORN .00009398 M (.0037 IN.) AT ONE POSITION
11	4	11.1	"	"	"	"	"	SAME AS BUILD 10	GOOD CONDITION WITH NEGLIGIBLE WEAR, EXCEPT TURBINE END SECONDARY BEARING PAD WORN .00023114 M (.0091 IN.) AT ONE POSITION AND CARBON ID WORN .00001524 TO .00006858 M (.0006 TO .0027 IN.) ON OUTLET SIDE; TURBINE END SECONDARY SLEEVE SURFACE WORN .000006635 TO .000001524 M (.000025 TO .000060 IN.)
12	43	107.5	"	"	"	"	"	SAME AS BUILD 11	GOOD CONDITION WITH NEGLIGIBLE WEAR EXCEPT TURBINE END SECONDARY SEAL; BEARING PAD WORN ADDITIONAL .00030226 M (.0119 IN.) FOR A TOTAL OF .0003937 M (.0155 IN.); INLET DIAMETER WAS WORN .00027178 M (.0107 IN.); THE OUTLET DIAMETER WAS WORN .0002464 M (.0097 IN.) SHAFT SLEEVE SURFACE WAS WORN .00000381 TO .00000762 M (.00015 TO .0003 IN.); WEAR MAY BE RESULT OF TESTER FAILURE
13	60	150	7R0011525 047909	7R0011526 047909	7R0011525 074907	7R0011526 047907	RS005092X-005 1	NEW SEAL RINGS AND SHAFT SEAL SLEEVE; SAME HOUSING AS BUILD 12	GOOD CONDITION WITH NEGLIGIBLE WEAR EXCEPT TURBINE END SECONDARY SEAL; BEARING PAD WORN .00039116 M (.0154 IN.) CARBON ID WORN .0001905 M (.0075 IN.) AT OUTLET AND .0001498M (.0059 IN.) AT INLET; CARBON CHIPPED AT THE OUTLET EDGE; SHAFT SLEEVE WORN .000003048 M (.00012 IN.)
14	60	150	"	"	"	"	"	SAME AS BUILD 13	GOOD CONDITION WITH NEGLIGIBLE WEAR EXCEPT TURBINE END SECONDARY SEAL; AXIAL DAM AND BEARING PAD WORN .001044 M (.0411 IN.) AT OUTLET AND .0009652 M (.0380 IN.) AT INLET; SHAFT SLEEVE WORN .00003556 M (.0014 IN.)

TABLE 7. (Continued)

BUILD NO.	STARTS	TIME MIN.	PUMP END SEAL PRIMARY PN SN	PUMP END SEAL SECONDARY PN SN	TURBINE END SEAL PRIMARY PN SN	TURBINE END SEAL SECONDARY PN SN	MATING RING PN SN	HARDWARE CONDITION PRETEST	HARDWARE CONDITION POST TEST
15	19	47.5	7R0011525 047909	7R0011526 047909	7R0011525 047907	7R0011525 047907	RS005092X-005 1	SAME AS BUILD 14	PUMP END PRIMARY SEAL IN GOOD CONDITION WITH NEGLIGIBLE WEAR; PUMP END SECONDARY SEAL SHOWED CONTACT PATTERN HALF WAY ACROSS BORE ON DOWNSTREAM SIDE AND SOME CHIPPING ON THE DOWNSTREAM EDGE OF THE FACE AT THE BORE; TURBINE END PRIMARY SEAL SHOWED UNIFORM CONTACT OVER 90% OF THE BORE TOWARD THE DOWNSTREAM EDGE BUT NEGLIGIBLE WEAR THE TURBINE END SECONDARY SEAL SHOWED HEAVY RUBBING AND CHIPPING ON THE BORE AND NEARLY COMPLETELY WORN OFF BEARING PADS; SHAFT SLEEVE WAS WORN .0000127 M (.0005 IN.)
16	60	150	7R0011525 047905	7R0011526 047905	7R0011525 047908	7R0011526 047903	RS005092X-005 2	ALL NEW HARDWARE	GOOD CONDITION WITH NEGLIGIBLE WEAR EXCEPT FOR THE TURBINE END SECONDARY SEAL: BEARING PAD WORN .0003886 M (.0153 IN.); CARBON ID WORN .00099 M (.039 IN.) AT THE OUTLET AND .00009652 M (.0038 IN.) AT THE INLET: TURBINE END SECONDARY SLEEVE SURFACE WORN .00000579 M (.000228 IN.)
17	60	150	"	"	"	"		SAME AS BUILD 16	BOTH THE PUMP END PRIMARY SEAL AND THE TURBINE END PRIMARY SEAL IN GOOD CONDITION WITH NEGLIGIBLE WEAR; PUMP END AND THE TURBINE END SECONDARY SEALS SHOW WEAR ON THE PAD HEIGHT DIMENSION AND THE CARBON BORE, AS WELL AS SOME CHIPPING ON THE DOWNSTREAM EDGE OF THE BORE; SHAFT SLEEVE WORN .0000087122 M (.000343 IN.)
18	4	10	"	"	"	"	"	SAME AS BUILD 17	BOTH PUMP END PRIMARY AND TURBINE END PRIMARY SEALS IN GOOD CONDITION WITH NEGLIGIBLE WEAR; SOME WEAR IS VISIBLE ON THE PAD HEIGHT AND CARBON BORE DIMENSIONS OF THE PUMP END SECONDARY AND TURBINE END SECONDARY SEALS

TABLE 7 (Concluded)

BUILD NO.	STARTS	TIME MIN.	PUMP END SEAL PRIMARY PN SN	PUMP END SEAL SECONDARY PN SN	TURBINE END SEAL PRIMARY PN SN	TURBINE END SEAL SECONDARY PN SN	MATING RING PN SN	HARDWARE CONDITION PRETEST	HARDWARE CONDITION POST TEST
19	15	37.5	7R0011525 047905	7R0011526 047905	7R0011525 047908	7R001526 047903	RS005092X-005 2	SAME AS BUILD 18	NO INSPECTION
20	41	102.5	"	"	"	"	"	SAME AS BUILD 19	BOTH PUMP END PRIMARY AND TURBINE END PRIMARY SEALS IN GOOD CONDITION WITH LITTLE WEAR; PUMP END AND TURBINE END SECONDARY SEALS SHOW WEAR ON THE PAD HEIGHT DIMENSION AND THE CARBON BORE, AS WELL AS SOME CHIPPING ON THE DOWN-STREAM EDGE OF THE BORE; SHAFT WORN .00000381 M (.00015 IN.)

TABLE 8. RAYLEIGH STEP SEAL INSPECTION SUMMARY - U.S. CUSTOMARY UNITS

	DIAMETRAL CLEARANCE (PRETEST), IN.				LIFT PAD DEPTHS (PRE/POSTTEST), IN.																DIAMETRAL WEAR, IN.			
					TURBINE END								PUMP END											
	TURBINE END		PUMP END		PRIMARY				SECONDARY				PRIMARY				SECONDARY				TURBINE END		PUMP END	
BUILD NO.	PRIMARY	SECONDARY	PRIMARY	SECONDARY	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	PRIMARY	SECONDARY	PRIMARY	SECONDARY
1	.0039	.0039	.0041	.0039	.00075 0	.00075 0	.00075 0	.00075 0	.0005 .0004	.0005 0	.00075 .0003	.0006 .0002	.0010 .0005	.0008 .0005	.00075 .0005	.00075 .0006	.0006 0	.0005 0	.0006 0	.0007 .0002	.0022	.0009	.0006	.0023
2	.0039	.0039	.0041	.0039	0 0	0 0	0 0	0 0	.0004 .0001	0 0	.0003 .0002	.0002 .0001	.0005 .0005	.0005 .0005	.0005 .0003	.0006 .0005	0 0	0 0	0 0	.0002 0	.0001	.0001	.0003	.0016
3	*	*	*	*	0 0	0 0	0 0	0 0	.0001 0	0 0	.0002 0	.0002 0	.0005 .0003	.0005 ----	.0003 .0002	.0005 .0001	0 0	0 0	0 0	0 0	.0004	.0006	.0007	.0009
4	*	*	*	*	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	.0003 0	---- .0003	.0002 0	.0001 0	0 0	0 0	0 0	0 0	.0001	0	.0002	.0002
5	.0040	.0038	.0041	.0039	.0005 .0005	.0005 .0005	.0007 .0006	.0007 .0007	.0006 0	.0007 0	.0006 0	.0005 0	.00075 .00075	.0010 .0007	.00075 .00075	.00075 .00075	.00075 .00055	.0010 .00075	.0009 .0007	.0008 .00075	.0005	.0008	.0001	.0008
6	*	*	*	*	.0005 .0004	.0005 .0005	.0006 .0005	.0007 .0005	0 0	0 0	0 0	0 0	.00075 .0006	.0007 .00075	.00075 .00075	.00075 .0006	.00055 .00055	.00075 .0006	.0007 .0006	.00075 .00055	0	.0002	0	.0001
7	.0038	.0035	.0038	.0036	.0005 .0001	.0007 .0002	.0007 .0002	.0007 .0007	.0007 0	.00075 0	.0007 0	.0005 .0003	.0008 .0005	.0008 .0002	.0007 .0004	.0007 .00065	.0006 .0002	.0007 .0002	.0007 .0001	.0007 .0005	.0007	.0023	.0006	.0011
8	*	*	*	*	.0001 .0005	.0002 .0002	.0002 0	.0007 .0005	0 0	0 0	0 0	.0003 .00025	.0005 .0005	.0002 .0002	.0004 .0004	.00065 .00065	.0002 .00015	.0002 .0002	.0001 .0001	.0005 .0005	.0008	.0030	.0003	.0002
9	.0054	.0089	.0046	.0005	.00005 0	.0002 0	0 0	.0005 0	0 0	0 0	0 0	.00025 0	.0005 .00025	.0002 0	.0004 0	.00065 .0005	.00015 0	.0002 0	.0001 0	.0005 .0003	.0142	.0006	.0009	.0005

*NO MEASUREMENT TAKEN

TABLE 9. RAYLEIGH STEP SEAL INSPECTION SUMMARY - SI UNITS

BUILD NO.	DIAMETRAL CLEARANCE (PRETEST), M				LIFT PAD DEPTHS (PRE/POSTTEST), M																DIAMETRAL WEAR, M			
					TURBINE END								PUMP END											
	TURBINE END		PUMP END		PRIMARY				SECONDARY				PRIMARY				SECONDARY				TURBINE END		PUMP END	
	PRIMARY	SECONDARY	PRIMARY	SECONDARY	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	PRIMARY	SECONDARY	PRIMARY	SECONDARY
1	.000099	.000099	.000104	.000099	.000019 0	.000017 0	.000019 0	.000015 0	.000012 .000010	.000012 0	.000019 .000007	.000015 .000005	.000025 .000012	.000020 .000012	.000019 .000012	.000019 .000015	.000015 0	.000012 0	.000015 0	.000017 .000005	.000055	.000022	.000015	.000058
2	.000099	.000099	.000114	.000099	0 0	0 0	0 0	0 0	.000010 .000002	0 0	.000007 .000005	.000005 .000002	.000012 .000012	.000012 .000012	.000012 .000007	.000015 .000012	0 0	0 0	0 0	.000005 0	.000002	.000002	.000007	.000040
3	*	*	*	*	0 0	0 0	0 0	0 0	.000002 0	0 0	.000005 0	.000005 0	.000012 .000007	.000012 ----	.000007 .000005	.000012 .000002	0 0	0 0	0 0	0 0	.000010	.000015	.000017	.000022
4	*	*	*	*	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	.000007 0	---- .000007	.000005 0	.000007 0	0 0	0 0	0 0	0 0	.000002	0	.000005	.000005
5	.000101	.000096	.000104	.000099	.000012 .000012	.000012 .000012	.000017 .000015	.000017 .000017	.000015 0	.000017 0	.000015 0	.000012 0	.000019 .000019	.000025 .000017	.000019 .000019	.000019 .000019	.000019 .000013	.000025 .000019	.000022 .000017	.000020 .000019	.000025	.000020	.000002	.000020
6	*	*	*	*	.000012 .000010	.000012 .000012	.000015 .000012	.000017 .000012	0 0	0 0	0 0	0 0	.000019 .000015	.000017 .000019	.000019 .000019	.000019 .000015	.000013 .000013	.000019 .000015	.000017 .000015	.000019 .000013	0	.000005	0	.000002
7	.000096	.000088	.000094	.000091	.000012 .000002	.000017 .000005	.000017 .000005	.000017 .000017	.000017 0	.000019 0	.000017 0	.000012 .000007	.000020 .000012	.000020 .000005	.000017 .000010	.000017 .000016	.000015 .000005	.000017 .000005	.000017 .000002	.000017 .000012	.000017	.000058	.000018	.000027
8	*	*	*	*	.000002 .000001	.000005 .000005	.000005 0	.000017 .000012	0 0	0 0	0 0	.000007 .000006	.000012 .000012	.000005 .000005	.000010 .000010	.000016 .000016	.000005 .000003	.000005 .000005	.000002 .000002	.000012 .000012	.000020	.000076	.000007	.000005
9	.000137	.000022	.000116	.000127	.000001 0	.000005 0	0 0	.000012 0	0 0	0 0	0 0	.000006 0	.000012 .000006	.000005 0	.000010 0	.000016 .000012	.000003 0	.000005 0	.000002 0	.000012 .000007	.000360	.000015	.000022	.000012

*NO MEASUREMENTS TAKEN

TABLE 10. TAPERED BORE SEAL INSPECTION SUMMARY - U.S. CUSTOMARY UNITS

BUILD NO.	POSITION NO. (120° EA.)	PUMP END SEAL, IN. (PRE/POST TEST)						TURBINE END SEAL, IN. (PRE/POST TEST)						SHAFT SLEEVE DIA. IN.
		PRIMARY			SECONDARY			PRIMARY			SECONDARY			
		INLET DIA	OUTLET DIA	(2) PAD HEIGHT	INLET DIA	OUTLET DIA	(2) PAD HEIGHT	INLET DIA	OUTLET DIA	(2) PAD HEIGHT	INLET DIA	OUTLET DIA	(2) PAD HEIGHT	
10	1 (1)	2.5478	2.5458	.0175	2.5443	2.5432	-	2.5481	2.5458	.0180	2.5458	2.5433	.0180	2.5363
		2.5473	2.5454	.0180	2.5442	2.5426	.0152	2.5477	2.5463	.0172	2.5433	2.5416	.0143	
	2 (1)	2.5478	2.5458	.0175	2.5443	2.5432	-	2.5481	2.5458	.0180	2.5458	2.5433	.0180	
		2.5470	2.5458	.0175	2.5436	2.5429	.0152	2.5474	2.5462	.0170	2.5441	2.5430	.0168	
	3 (1)	2.5478	2.5458	.0175	2.5443	2.5432	-	2.5481	2.5458	.0180	2.5488	2.5433	.0180	
		2.5469	2.5456	.0180	2.5436	2.5421	.0163	2.5452	2.5457	.0179	2.5441	2.5428	.0176	
11	1	2.5473	2.5454	.0180	2.5442	2.5426	.0152	2.5477	2.5463	.0172	2.5433	2.5416	.0143	2.5363
		2.5469	2.5455	.0179	2.5442	2.5432	.0141	2.5474	2.5458	.0165	2.5465	2.5443	.0052	
	2	2.5470	2.5458	.0175	2.5436	2.5429	.0152	2.5474	2.5462	.0170	2.5441	2.5430	.0168	
		2.5469	2.5460	.0191	2.5429	2.5427	.0158	2.5466	2.5459	.0163	2.5431	2.5446	.0175	
	3	2.5469	2.5456	.0180	2.5436	2.5421	.0163	2.5452	2.5457	.0179	2.5441	2.5428	.0176	
		2.5471	2.5456	.0191	2.5430	2.5423	.0158	2.5473	2.5455	.0163	2.5435	2.5434	.0175	
12	1	2.5469	2.5455	.0179	2.5442	2.5432	.0141	2.5474	2.5458	.0165	2.5465	2.5443	.0052	2.5363
		2.5465	2.5467	.0178	2.5443	2.5434	.0140	2.5477	2.5462	.0165	2.5530	2.5512	.0025	
	2	2.5469	2.5460	.0191	2.5429	2.5427	.0158	2.5466	2.5459	.0163	2.5431	2.5446	.0175	
		2.5475	2.5461	.0179	2.5434	2.5427	.0139	2.5480	2.5467	.0161	2.5482	2.5476	.0056	
	3	2.5471	2.5456	.0191	2.5430	2.5423	.0158	2.5473	2.5455	.0163	2.5435	2.5434	.0175	
		2.5474	2.5459	.0178	2.5436	2.5426	.0151	2.5481	2.5461	.0167	2.5542	2.5531	.0098	
13	1	2.5455	2.5455	.0181	2.5447	2.5427	.0184	2.5474	2.5458	.0177	2.5455	2.5437	.0185	2.5361
		2.5466	2.5455	.0182	2.5443	2.5429	.0162	2.5481	2.5477	.0176	2.5496	2.5488	.0031	2.5360
	2	2.5465	2.5446	.0174	2.5441	2.5429	.0176	2.6473	2.5459	.0173	2.5451	2.5451	.0189	2.5360
		2.5465	2.5463	.0178	2.5448	2.5442	.0123	2.5478	2.5471	.0177	2.5510	2.5513	.0055	2.5360
	3	2.5464	2.5453	.0182	2.5438	2.5425	.0177	2.5476	2.5460	.0175	2.5462	2.5447	.0183	2.5360
		2.5474	2.5471	.0179	2.5445	2.5437	.0122	2.5477	2.5473	.0179	2.5434	2.5436	.0060	2.5359
14	1	2.5466	2.5455	.0182	2.5443	2.5429	.0162	2.5481	2.5477	.0176	2.5496	2.5488	.0031	2.5361
		2.5456	2.5461	.0184	2.5436	2.5419	.0138	2.5491	2.547[illegible]	.0172	2.5804	2.5813	.0022	2.5361
	2	2.5465	2.5463	.0178	2.5448	2.5442	.0123	2.5478	2.5471	.0177	2.5510	2.5513	.0055	2.5360
		2.5461	2.5462	.0176	2.5448	2.5440	.0062	2.5481	2.5472	.0172	2.5810	2.5823	.0013	2.5361
	3	2.5474	2.5471	.0179	2.5445	2.5437	.0122	2.5477	2.5473	.0179	2.5434	2.5436	.0060	2.5359
		2.5473	2.5471	.0183	2.5446	2.5431	.0077	2.5483	2.5474	.0176	2.5842	2.5858	.0012	2.5369

(1) PRETEST MEASUREMENTS ARE AT ONE POSITION
(2) AXIAL BEARING PAD

TABLE 10. (Concluded)

BUILD NO.	POSITION NO. (120° EA.)	PUMP END SEAL, IN. (PRE/POST TEST) PRIMARY INLET DIA	OUTLET DIA	PAD HEIGHT	SECONDARY INLET DIA	OUTLET DIA	PAD HEIGHT	TURBINE END SEAL, IN. (PRE/POST TEST) PRIMARY INLET DIA	OUTLET DIA	PAD HEIGHT	SECONDARY INLET DIA	OUTLET DIA	PAD HEIGHT	SHAFT SLEEVE DIA. IN.
15	1	2.5456 2.5468	2.5461 2.5457	.0184 .0184	2.5436 2.5425	2.5419 2.5431	.0138 .0130	2.5491 2.5476	2.5479 2.5471	.0172 .0172	2.5804 2.5854	2.5813 2.5853	.0022 .0026	2.5358
	2	2.5461 2.5452	2.5462 2.5447	.0176 .0181	2.5448 2.5442	2.5440 2.5442	.0062 .0045	2.5481 2.5475	2.5472 2.5468	.0172 .0170	2.5810 2.5799	2.5823 2.5797	.0013 .0005	2.5359
	3	2.5473 2.5470	2.5471 2.5468	.0183 .0184	2.5446 2.5443	2.5431 2.5430	.0077 .0087	2.5483 2.5472	2.5474 2.5470	.0176 .0176	2.5842 2.5739	2.5858 2.5756	.0012 .0003	2.5359
16	1	2.5476 2.5475	2.5460 2.5459	.0171 .0169	2.5442 2.5442	2.5427 2.5432	.0178 .0152	2.5452 2.5462	2.5466 2.5467	.0186 .0180	2.5450 2.5437	2.5432 2.5429	.0177 .0025	2.5362 2.5369
	2	2.5472 2.5466	2.5460 2.5455	.0170 .0165	2.5438 2.5448	2.5429 2.5440	.0177 .0159	2.5451 2.5483	2.5463 2.5452	.0187 .0181	2.5450 2.5456	2.5434 2.5445	.0176 .0065	2.5362 2.5370
	3	2.5473 2.5471	2.5459 2.5457	.0169 .0165	2.5442 2.5433	2.5433 2.5421	.0174 .0161	2.5452 2.5463	2.5467 2.5450	.0186 .0181	2.5438 2.5476	2.5429 2.5468	.0173 .0020	2.5361 2.5370
17	1	2.5475 2.5463	2.5459 2.5479	.0169 .0176	2.5442 2.5526	2.5432 2.5515	.0152 .0033	2.5462 2.5468	2.5467 2.5468	.0180 .0173	2.5437 2.5487	2.5429 2.5485	.0025 .0042	2.5369 2.5360
	2	2.5466 2.5452	2.5455 2.5451	.0165 .0180	2.5448 2.5483	2.5440 2.5429	.0159 .0085	2.5483 2.5418	2.5452 2.5436	.0181 .0167	2.5456 2.5439	2.5445 2.5456	.0065 .0026	2.5370 2.5360
	3	2.5471 2.5468	2.5457 2.5464	.0165 .0182	2.5433 2.5472	2.5421 2.5487	.0161 .0047	2.5463 2.5453	2.5450 2.5468	.0181 .0160	2.5476 2.5455	2.5468 2.5469	.0020 .0031	2.5370 2.5360
18	1	2.5463	2.5479	.0176	2.5526	2.5525	.0033	2.5468	2.5468	.0173	2.5487	2.5485	.0042	2.5360
	2	2.5452	2.5451	.0180	2.5483	2.5429	.0085	2.5418	2.5436	.0167	2.5439	2.5456	.0026	2.5360
	3	2.5468	2.5464	.0182	2.5472	2.5487	.0047	2.5453	2.5468	.0160	2.5455	2.5469	.0031	2.5360
19	NO PRETEST MEASUREMENTS TAKEN													
20 (POST TEST)	1	2.5475	2.5470	.0183	2.5455	2.5446	.0022	2.5479	2.5467	.0164	2.5485	2.5472	.0015	2.5364
	2	2.5472	2.5461	.0184	2.5456	2.5445	.0048	2.5459	2.5450	.0155	2.5463	2.5449	.0005	2.5360
	3	2.5473	2.5466	.0183	2.5487	2.5475	.0011	2.5479	2.5473	.0154	2.5481	2.5467	.0006	2.5362

TABLE 11. TAPERED BORE SEAL INSPECTION SUMMARY - SI UNITS

BUILD NO.	POSITION NO. (2.0944 RAD EA)	PUMP END SEAL, M (PRE/POST TEST) PRIMARY INLET DIA	PRIMARY OUTLET DIA	PRIMARY PAD HEIGHT	SECONDARY INLET DIA	SECONDARY OUTLET DIA	SECONDARY PAD HEIGHT	TURBINE END SEAL, M (PRE/POST TEST) PRIMARY INLET DIA	PRIMARY OUTLET DIA	PRIMARY PAD HEIGHT	SECONDARY INLET DIA	SECONDARY OUTLET DIA	SECONDARY PAD HEIGHT	SHAFT SLEEVE DIA., M
10	1 (*)	.064714 .064701	.064663 .064653	.00044 .00045	.064625 .064622	.064597 .064582	- .00038	.064721 .064711	.064663 .064676	.00045 .00043	.064663 .064599	.064599 .064556	.00045 .00036	.06442
	2 (*)	.064714 .064693	.064663 .064663	.00044 .00044	.064625 .064607	.064597 .064589	- .00038	.064721 .064703	.064663 .046473	.00045 .00043	.064663 .064620	.064599 .064592	.00045 .00042	
	3 (*)	.064714 .064691	.064663 .064658	.00045 .00045	.064625 .064607	.064597 .-64569	- .00041	.064721 .064648	.064663 .064660	.00045 .00045	.064739 .064620	.064599 .064587	.00045 .00044	
11	1	.064701 .064691	.064653 .064655	.00045 .00044	.064622 .064622	.064582 .064597	.00038 .00035	.064711 .064703	.064676 .064663	.00043 .00041	.064599 .064681	.064556 .064625	.00036 .00013	.06442
	2	.064693 .064691	.064663 .064668	.00048 .00045	.064607 .064589	.064589 .064584	.00038 .00040	.064703 .064683	.064673 .064665	.00043 .00041	.064620 .064594	.064592 .064632	.00042 .00044	
	3	.064691 .064696	.-64658 .064658	.00048 .00045	.064607 .064592	.064569 .064574	.00041 .00040	.064648 .064701	.064660 .064655	.00045 .00041	.064620 .064604	.064587 .064602	.00044 .00044	
12	1	.64691 .064681	.064655 .064686	.00045 .00048	.064622 .064625	.064597 .064602	.00035 .00035	.064703 .064711	.064663 .064673	.00041 .00041	.064681 .064592	.064625 .064800	.00013 .00006	.06442
	2	.064691 .064706	.064658 .064670	.00045 .00048	.064589 .064602	.064584 .064584	.00040 .00035	.064683 .064719	.064665 .064686	.00041 .00040	.064594 .064724	.064632 .064709	.00044 .00014	
	3	.064691 .064703	.064658 .064665	.00045 .00045	.064592 .064607	.064574 .064582	.00040 .00038	.064701 .064721	.064655 .064670	.00041 .00042	.064604 .064876	.064602 .064848	.00044 .00024	
13	1	.064655 .064683	.064655 .064655	.00045 .00046	.064635 .064625	.064584 .-64589	.00046 .00041	.064703 .064721	.064663 .064711	.00044 .00044	.064655 .064759	.064609 .064739	.00046 .00078	.06441 .06441
	2	.064681 .064681	.064632 .064676	.00044 .00045	.064620 .064637	.064589 .064622	.00044 .00031	.064701 .064714	.064665 .064696	.00043 .00044	.064645 .064795	.064645 .064803	.00048 .00013	.06441 .06441
	3	.064678 .064670	.064650 .064696	.00046 .00045	.064612 .064630	.064657 .064609	.00044 .00030	.064709 .064711	.064668 .064701	.00044 .00045	.064673 .064602	.064635 .064607	.00046 .00015	.06441 .06441
14	1	.064683 .064658	.064655 .064677	.00046 .00046	.064625 .064607	.064589 .064564	.00041 .00035	.064721 .064747	.064711 .064716	.00044 .00043	.064759 .065542	.064739 .065565	.00007 .00005	.06441 .06441
	2	.064681 .064681	.064676 .064676	.00045 .00045	.064637 .064637	.064622 .064617	.00031 .00015	.064714 .064721	.064696 .064698	.00044 .00043	.064795 .065557	.064803 .065590	.00013 .00003	.064414 .064416
	3	.064703 .064701	.064696 .064696	.00045 .00046	.064630 .064632	.064609 .064594	.00030 .00019	.064711 .064726	.064701 .064703	.00045 .00044	.064602 .065638	.064607 .065679	.00015 .00003	.064411 .064414

(*) PRETEST MEASUREMENTS ARE AT ONE POSITION

TABLE 11. (Concluded)

BUILD NO.	POSITION NO. (2.0944 RAD EA)	PUMP END SEAL, M (PRE/POST TEST) PRIMARY INLET DIA	OUTLET DIA	PAD HEIGHT	SECONDARY INLET DIA	OUTLET DIA	PAD HEIGHT	TURBINE END SEAL, M (PRE/POST TEST) PRIMARY INLET DIA	OUTLET DIA	PAD HEIGHT	SECONDARY INLET DIA	OUTLET DIA	PAD HEIGHT	SHAFT SLEEVE DIA., M
15	1	.064658 .064688	.064670 .064660	.00046 .00046	.064607 .064579	.064564 .064594	.00035 .00033	.064747 .064709	.064716 .064696	.00043 .00043	.065542 .065669	.065572 .065666	.00005 .00006	.064409
	2	.064670 .064648	.064673 .064635	.00044 .00045	.064637 .064622	.064617 .064622	.00015 .00011	.064721 .064706	.064698 .064688	.00043 .00043	.065557 .065529	.065590 .065524	.00003 .00001	.064411
	3	.064701 .064693	.064696 .064688	.00046 .00046	.064632 .064625	.064594 .064592	.00019 .00022	.064726 .064698	.064703 .064693	.00044 .00044	.065638 .065377	.064679 .064520	.00003 .00007	.064411
16	1	.064709 .064706	.064668 .064665	.00043 .00042	.064622 .064622	.064584 .064597	.00045 .00038	.064648 .064673	.064683 .064686	.00047 .00045	.064643 .064609	.064597 .064589	.00044 .00006	.064419 .064437
	2	.064693 .064683	.064668 .064655	.00043 .00041	.064612 .064637	.064589 .064617	.00044 .00040	.064645 .064726	.064676 .064648	.00047 .00045	.064643 .064658	.064602 .064630	.00044 .00061	.064419 .064439
	3	.064701 .064696	.064665 .064660	.00042 .00041	.064622 .064599	.064599 .064569	.00044 .00040	.064648 .064676	.064686 .064643	.00047 .00045	.064612 .064709	.064589 .064688	.00043 .00005	.064416 .064439
17	1	.064706 .064676	.064665 .064716	.00042 .00044	.064622 .064836	.064597 .064808	.00038 .00008	.064673 .064688	.064686 .064688	.00045 .00043	.064609 .064736	.064589 .064731	.00006 .00010	.064437 .064414
	2	.064683 .064648	.064655 .064645	.00041 .00045	.064637 .064726	.064617 .064589	.00040 .00021	.064726 .064561	.064648 .064607	.00045 .00042	.064658 .064615	.064630 .064658	.00016 .00006	.064439 .064414
	3	.064696 .064688	.064660 .064678	.00041 .00046	.064599 .064698	.064569 .064736	.00040 .00011	.064676 .064650	.064643 .064688	.00045 .00040	.064709 .064655	.064688 .064691	.00005 .00007	.064439 .064414
18	1	.064676	.064716	.00044	.064836	.064833	.00008	.064688	.064688	.00043	.064736	.064731	.00010	.064414
	2	.064648	.064645	.00045	.064726	.064589	.00021	.064561	.064607	.00042	.064615	.064658	.00006	.064414
	3	.064688	.064678	.00046	.064698	.064736	.00011	.064650	.064688	.00040	.064655	.064691	.00007	.064414
19	NO PRETEST MEASUREMENTS TAKEN													
20 (POSTTEST)	1	.064706	.064693	.00046	.064655	.064632	.00005	.064716	.064686	.00041	.064731	.064698	.00003	.064424
	2	.064698	.064671	.000467	.064658	.06463	.000122	.06466	.06464	.0003937	.064676	.06464	.0000127	.064414
	3	.064701	.064683	.000464	.064737	.06470	.000279	.064716	.064701	.0003911	.064721	.064686	.0000152	.064419

TABLE 12. HOT GAS TURBINE SEAL DATA SUMMARY - U.S. CUSTOMARY UNITS

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	PUMP END SEAL SEC DRAIN PR-PSIG	PUMP END SEAL LEAKAGE LB/SEC PRI	SEC	TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	TURBINE END SEAL SEC DRAIN PR-PSIG	TURBINE END SEAL LEAKAGE LB/SEC PRI	SEC	TOTAL
1	1	2.5	32000	70	240	5	0.5	.106	.085	.191	10	11.25	.121	.042	.163
"	2				464	15	0.5	.130	.089	.189	25	38.25	.208	.040	.248
"	3				970	32.5	0.5	.230	.095	.325	40	66.25	.315	.042	.357
2	4				960	62.5	1.5	.214	.091	.305	40	58.75	.288	.037	.325
"	5				1470	57.5	2.5	.343	.041	.384	72.5	105	.472	.020	.492
"	6	1.75			1950	85	10.6	.478	.026	.504	107.5	145	.650	.037	.687
3	7	2.5			1980	102.5	13	.536	.064	.600	107.5	145	.672	.043	.715
"	8				2500	145	8	.714	.101	.815	142.5	193.8	.869	.054	.923
"	9				3000	200	14.5	.952	.145	1.097	187.5	241.3	1.058	.085	1.143
4	10	2.5			2650	262.5	15.5	.881	.129	1.01	165.0	218.8	.986	.079	1.065
"	11				3025	307.5	24.5	1.036	.170	1.206	202.5	265.0	1.164	.096	1.260
"	12				3200	325	27.5	1.099	.177	1.276	217.5	141.3	1.230	.113	1.343
5	13	2.5	32000	420	525	20	0.75	.121	.085	.206	2.5	25	.151	.038	.189
"	14			492	1000	80	0.5	.234	.079	.373	8.75	81.25	.312	.062	.374
"	15			440	1525	123.75	7.25	.433	.081	.514	16.25	123.75	.450	.094	.544
"	16			303	2100	140	3.25	.548	.084	.632	22.5	151.25	.551	.091	.642
6	17	2.5	32000	284*	2575	175	6.0	.636	.082	.718	32.5	183.8	.684	.106	.790
"	18			245*	3175	211.3	5.25	.798	.081	.879	48.8	231.3	.829	.129	.958
"	19			232*	3500	225	3.75	.846	.081	.927	52.5	235	.886	.129	1.015
"	20			223*	3775	240	6.25	.932	.083	1.015	45	200	.770	.267	1.037
7	21	2.5	32000	368	3700	267.5	14.75	.984	.117	1.101	42.5	270	.954	.152	1.106
"	22			488	3700	315	35	1.062	.189	1.251	55	322.5	1.064	.229	1.293
"	23			450	3700	305	34	1.035	.182	1.217	56.25	310	1.052	.223	1.275
"	24			435	3625	302.5	33	1.098	.184	1.282	58.8	327.5	1.097	.232	1.329
"	25			490	3650	332.5	41.75	1.128	.223	1.351	61.25	360	1.182	.274	1.456
"	26	2.5	32000	440	3650	315	32.5	1.071	.184	1.255	63.8	350	1.160	.264	1.424
"	27			400	3725	335	36	1.186	.196	1.382	265	370	1.221	.290	1.511
"	28			460	3650	360	45	1.211	.230	1.441	325	405	1.285	.271	1.556
"	29			475	3650	365	47.8	1.229	.244	1.473	300	407.5	1.319	.268	1.587

*VALUES ARE LOWEST RECORDED. ACTUAL TEMPERATURE VARIANCE WAS FROM 425 TO 223 F

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	PUMP END SEAL SEC DRAIN PR-PSIG	PUMP END SEAL LEAKAGE LB/SEC PRI	PUMP END SEAL LEAKAGE LB/SEC SEC	PUMP END SEAL LEAKAGE LB/SEC TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	TURBINE END SEAL SEC DRAIN PR-PSIG	TURBINE END SEAL LEAKAGE LB/SEC PRI	TURBINE END SEAL LEAKAGE LB/SEC SEC	TURBINE END SEAL LEAKAGE LB/SEC TOTAL
8	30	2.5	32000	252	3475	116.3	17.5	.531	.097	.628	128.8	160	.612	.200	.812
"	31			212	3575	247.5	2.5	1.055	.085	1.140	232.5	237.5	.894	.471	1.365
"	32			210	3525	247.5	1.5	1.052	.084	1.136	290	305	1.119	.228	1.347
"	33			265	3450	265	12.5	1.067	.119	1.186	302.5	327.5	1.143	.260	1.403
"	34			230	3475	250	7.0	1.055	.098	1.153	287.5	317.5	1.131	.238	1.369
"	35			245	3450	252.5	7.5	1.052	.105	1.157	295	322.5	1.119	.235	1.354
"	36			190	3450	250	6.0	1.001	.087	1.088	215	222.5	.863	.463	1.326
"	37			215	3475	260	8.0	1.055	.097	1.152	290	305	1.121	.293	1.374
"	38			212	3500	262.5	6.0	1.055	.097	1.152	290	307.5	1.123	.253	1.376
"	39			210	3450	255	6.0	1.019	.093	1.112	285	295	1.158	.245	1.403
"	40			240	3450	272.5	10.5	1.064	.106	1.170	297.5	312.5	1.143	.272	1.415
"	41			240	3425	272.5	8.0	1.078	.103	1.181	295	310	1.129	.265	1.394
"	42			237	3400	270	7.5	1.066	.103	1.169	292.5	310	1.103	.260	1.363
"	43			220	3450	272.5	5.0	1.080	.096	1.176	295	310	1.117	.262	1.379
"	44			235	3425	272.5	7.5	1.078	.110	1.188	292.5	312.5	1.115	.266	1.381
"	45			222	3450	267.5	6.0	1.076	.101	1.177	290	307.5	1.113	.256	1.369
"	46			217	3425	265	10.0	1.076	.102	1.178	285	315	1.115	.256	1.371
"	47			260	3425	275	14.0	1.051	.119	1.170	230	255	.877	.266	1.143
"	48			217.5	3400	255	6.5	1.055	.096	1.151	280	312.5	1.094	.246	1.340
"	49			225	3325	252.5	7.0	1.030	.100	1.130	275	307.5	1.070	.245	1.315
"	50			210	3450	270	7.5	1.069	.096	1.165	292.5	325	1.139	.255	1.394
"	51			235	3375	262.5	7.5	1.082	.104	1.186	285	317.5	1.090	.250	1.340
"	52			270	3350	290	15	1.068	.127	1.195	227.5	250	.883	.513	1.396
"	53			247	3350	272.5	11	1.073	.114	1.187	282.5	310	1.109	.271	1.380
"	54			217	3350	262.5	7.5	1.067	.098	1.165	277.5	302.5	1.104	.262	1.366

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	SEC DRAIN PR-PSIG	LEAKAGE LB/SEC PRI	SEC	TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	SEC DRAIN PR-PSIG	LEAKAGE LB/SEC PRI	SEC	TOTAL
8 (CONTD)	55	2.5	32000	272	3450	297.5	16	1.179	.138	1.317	307.5	340	1.200	.296	1.496
"	56			230	3425	275	9	1.115	.111	1.226	290	315	1.151	.268	1.419
"	57			217	3400	265	8	1.098	.111	1.209	280	310	1.121	.262	1.383
"	58			290	3200	275	13.5	1.672	.125	1.797	287.5	310	1.089	.267	1.356
"	59			257	3325	275	9	1.589	.116	1.705	287.5	312.5	1.115	.256	1.371
"	60			235	3325	265	6.5	1.500	.109	1.609	277.5	300	1.092	.245	1.337
"	61			217	3375	265	9	1.078	.102	1.180	280	305	1.100	.262	1.362
"	62			215	3300	252.5	7.5	1.024	.090	1.114	265	290	1.061	.258	1.319
"	63			230	3325	265	9.5	1.055	.106	1.161	275	302.5	1.076	.272	1.348
"	64			225	3300	265	10	1.057	.098	1.155	280	305	1.092	.261	1.353
"	65			267	3300	280	15	1.073	.123	1.196	282.5	315	1.097	.283	1.380
"	66			237	3300	260	8.5	1.070	.104	1.174	272.5	305	1.092	.264	1.356
"	67			220	3325	257.5	7.5	1.069	.096	1.165	272.5	305	1.104	.257	1.361
"	68			220	3400	260	7.5	1.045	.099	1.144	272.5	305	1.104	.256	1.360
"	69			260	3300	270	13	1.079	.111	1.190	285	315	1.115	.273	1.388
"	70			212	3325	250	6	1.034	.096	1.130	265	292.5	1.069	.286	1.355
"	71			210	3325	250	7	1.044	.097	1.141	265	295	1.081	1.252	1.353
"	72			222	3350	257.5	9	1.063	.102	1.165	272.5	305	1.113	.256	1.369
"	73			215	3250	247.5	7	1.024	.096	1.120	260	290	1.061	.244	1.305
"	74			227	3275	252.5	8	1.030	.104	1.134	267.5	295	1.068	.255	1.323
"	75			220	3350	257.5	8.5	1.061	.110	1.171	270	302.5	1.098	.267	1.365
"	76			230	3275	252.5	9	1.025	.107	1.132	265	295	1.078	.263	1.341
"	77			255	3350	277.5	16.5	1.025	.122	1.225	225	252.5	.920	.525	1.445
"	78			232	3375	265	11	1.131	.107	1.238	275	310	1.125	.285	1.410
"	79			230	3300	255	9	1.104	.102	1.206	267.5	297.5	1.098	.272	1.370
"	80			250	3275	255	10	1.092	.106	1.198	265	295	1.084	.270	1.354

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	PUMP END SEAL SEC DRAIN PR-PSIG	PUMP END SEAL LEAKAGE LB/SEC PRI	PUMP END SEAL LEAKAGE LB/SEC SEC	PUMP END SEAL LEAKAGE LB/SEC TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	TURBINE END SEAL SEC DRAIN PR-PSIG	TURBINE END SEAL LEAKAGE LB/SEC PRI	TURBINE END SEAL LEAKAGE LB/SEC SEC	TURBINE END SEAL LEAKAGE LB/SEC TOTAL
9	81	2.5	32000	250	3325	277.5	14.5	1.066	.120	1.186	272.5	305	1.078	.295	1.373
"	82			240	3350	280	10.5	1.078	.107	1.185	277.5	310	1.100	.283	1.383
"	83			232	3375	272.5	11	1.082	.119	1.201	275	307.5	1.106	.287	1.393
"	84			295	3250	292.5	17.5	1.104	.128	1.232	287.5	322.5	1.100	.295	1.395
"	85			242	3300	272.5	9	1.080	.107	1.187	272.5	305	1.090	.283	1.323
"	86			242	3325	275	11.5	1.076	.111	1.187	280	307.5	1.086	.279	1.365
"	87			247	3300	275	11.5	1.059	.112	1.171	277.5	305	1.082	.275	1.357
"	88			227	3275	267.5	9.5	1.032	.108	1.140	267.5	302.5	1.061	.270	1.331
"	89			257	3275	280	12.5	1.050	.119	1.169	285	310	1.072	.280	1.352
"	90			227	3225	260	9.5	1.015	.104	1.119	262.5	292.5	1.069	.282	1.351
"	91			232	3300	282.5	12	1.055	.115	1.170	287.5	312.5	1.106	.295	1.401
"	92			232	3250	277.5	13.5	1.072	.122	1.194	285	305	1.111	.303	1.414
"	93			270	3275	292.5	16.5	1.123	.130	1.253	292.5	322.5	1.145	.305	1.450
"	94			232	3325	287.5	11.5	1.139	.118	1.257	285	317.5	1.164	.299	1.463
"	95			217	3275	282.5	10.5	1.119	.122	1.241	287.5	312.5	1.141	.292	1.433
"	96			215	3275	282.5	10	1.104	.122	1.226	277.5	310	1.127	.288	1.415
"	97			215	3250	282.5	9.5	1.088	.119	1.207	287.5	307.5	1.127	.286	1.413
"	98			220	3200	282.5	10	1.084	.124	1.208	275	307.5	1.094	.286	1.380
"	99			222	3200	285	10	1.084	.118	1.202	287.5	307.5	1.104	.282	1.386
"	100			227	3225	292.5	11	1.108	.110	1.218	295	315.0	1.117	.293	1.410
"	101			225	3225	287.5	16	1.115	.136	1.251	282.5	312.5	1.109	.315	1.424
"	102			200	3250	282.5	11	1.142	.120	1.262	280	307.5	1.135	.302	1.437
"	103			195	3250	285	10.5	1.161	.118	1.279	272.5	307.5	1.140	.302	1.442
"	104			217	3200	292.5	12.5	1.152	.127	1.279	280	310	1.131	.301	1.432
"	105			190	3175	282.5	10	1.154	.123	1.277	280	305	1.133	.295	1.428
"	106			197	3125	282.5	11	1.150	.124	1.274	270	305	1.129	.295	1.424
"	107	1.97		475	2725	305	35	1.079	.271	1.350	455	520	1.728	.642	2.370

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	PUMP END SEAL SEC DRAIN PR-PSIG	PUMP END SEAL LEAKAGE LB/SEC PRI	PUMP END SEAL LEAKAGE LB/SEC SEC	PUMP END SEAL LEAKAGE LB/SEC TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	TURBINE END SEAL SEC DRAIN PR-PSIG	TURBINE END SEAL LEAKAGE LB/SEC PRI	TURBINE END SEAL LEAKAGE LB/SEC SEC	TURBINE END SEAL LEAKAGE LB/SEC TOTAL
10	PRE 108 STATIC LEAK	-	0	85	500	65	1.5	.267	.041	.308	45	62.5	.283	.044	.327
"		-	0	75	1000	137.5	16.5	.548	.083	.631	100	20.0	.564	.092	.656
"	"	-	0	62.5	1500	210.0	33.5	.826	.129	.955	130	45.0	.844	.141	.985
"	"	-	0	62.5	2000	262.5	26.0	1.068	.216	1.284	170	67.5	1.138	.191	1.329
"	"	-	0	67.5	2400	285	49.0	1.204	.339	1.543	195	80.0	1.325	.223	1.548
"	"	-	0	77.5	2900	392.5	41.5	1.539	.303	1.842	415	122.5	1.538	.346	1.884
"	108	2.5	29500	432	525	52.5	.5	.190	.089	.279	57.5	2.5	.220	.038	.258
"	109	2.5	29500	500+	975	110	.5	.336	.085	.421	115	17.5	.365	.060	.425
"	110	2.5	29750	490	1500	200	1.5	.587	.084	.671	195	50.0	.607	.132	.739
"	111	2.5	29500	470	1950	252	9.0	.760	.087	.847	262	62.5	.768	.150	.918
11	112	2.7	29000	405	2475	285	40.5	.965	.152	1.117	300	90.0	.963	.216	1.179
"	113	2.9	29000	437	2950	375	19.5	1.198	.088	1.286	385	85.0	1.183	.201	1.384
"	114	2.5	29000	367	3250	405	30.0	1.341	.236	1.577	407	107	1.330	.258	1.588
"	115	3.0	29000	450	3425	395	29.0	1.241	.210	1.451	410	117	1.247	.260	1.507
12	116	2.5	29500	493.5	3400	371	35.7	1.150	.242	1.392	421	131	1.250	.275	1.525
"	117		28750	465	3210	376	21.5	1.139	.185	1.324	380	137.5	1.143	.319	1.462
"	118		28600	452	3500	400	22.5	1.231	.207	1.438	403.5	156	1.218	.355	1.573
"	119		29150	497	3700	413.5	25	1.260	.208	1.468	462.5	150	1.259	.347	1.606
"	120		28150	457.5	3575	428.5	28.2	1.290	.208	1.498	468.5	146	1.321	.343	1.664
"	121		29100	496	3500	425	26	1.239	.214	1.453	471	122.5	1.326	.284	1.61
"	122		30500	468.5	3700	428.5	30	1.299	.232	1.531	457.5	160	1.262	.364	1.626
"	123		28500	485	3750	405	28	1.219	.229	1.448	456	155	1.230	.362	1.592
"	124		26600	480	3585	425	26.5	1.292	.233	1.525	460	141	1.205	.333	1.538
"	125		28150	500	3585	410	31.5	1.308	.242	1.55	460	149	1.264	.313	1.577
"	126		28000	411	3525	392.5	26.7	1.353	.213	1.566	445	155	1.299	.354	1.653
"	127		28000	500	3575	428.5	30	1.301	.219	1.52	485	140	-	.322	-

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	PUMP END SEAL SEC DRAIN PR-PSIG	PUMP END LEAKAGE LB/SEC PRI	PUMP END LEAKAGE LB/SEC SEC	PUMP END LEAKAGE LB/SEC TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	TURBINE END SEAL SEC DRAIN PR-PSIG	TURBINE END LEAKAGE LB/SEC PRI	TURBINE END LEAKAGE LB/SEC SEC	TURBINE END LEAKAGE LB/SEC TOTAL
12	128	2.5	29000	500	3500	420	28	1.269	.202	1.471	480	130	1.339	.325	1.655
"	129		29000	500	3450	418.5	26.7	1.276	.202	1.478	479	131	1.298	.280	1.578
"	130		29000	500	3685	412.5	30.5	1.247	.2186	1.465	470	128.5	1.285	.273	1.558
"	131		27850	460	34150	422.5	30.5	1.307	.2091	1.516	485	130	1.312	.280	1.592
"	132		28650	456	3600	385	26.3	1.263	.206	1.469	440	155	1.225	.337	1.562
"	133		29000	468.5	3625	385	26	1.272	.2016	1.474	442	150	1.198	.337	1.935
"	134		29000	490	3535	425	26	1.234	.2174	1.451	460	142.5	1.204	.312	1.516
"	135		29000	495	3510	425	28	1.234	.2245	1.458	460	150	1.252	.334	1.586
"	136		29000	500	3525	425	30	1.234	.2173	1.451	462	160	1.222	.349	1.571
"	137		29000	447.5	3475	423.5	29.5	1.258	.2189	1.477	460	148.5	1.274	.331	1.605
"	138		28750	453.5	3435	422.5	28	1.252	.2097	1.462	445	163.5	1.203	.357	1.56
"	139		28600	427.5	3510	407.5	31	1.240	.2296	1.469	440	151	1.206	.350	1.556
"	140		28750	500	3500	430	29	1.200	.2256	1.426	450	180	1.149	.381	1.53
"	141		29000	445	3350	360	24.5	1.122	.2337	1.356	363	176.2	.986	.399	1.385
"	142		29000	430	3535	410	32.5	1.247	.2354	1.482	422	195	1.154	.444	1.598
"	143		28500	421.5	3550	414	32	1.273	.2280	1.501	418	190.7	1.159	.433	1.592
"	144		29000	470	3300	360	29	1.084	.244	1.328	340	181.2	.9398	.419	1.359
"	145		29600	505	3600	422.5	28.3	1.239	.223	1.462	452	205	1.146	.435	1.581
"	146		29500	495	35[illegible]0	427.5	28.2	1.239	.227	1.466	458	202.5	1.200	.431	1.631
"	147		29000	481	3540	410	28	1.209	.220	1.209	420	224.5	1.083	.476	1.559
"	148		29000	497	3585	417.5	28.2	1.258	.227	1.485	435	226.2	1.121	.478	1.599
"	149		27400	482.5	3540	420	28	1.270	.233	1.503	482	165.5	1.274	.363	1.637
"	150		29000	500	3590	409	28	1.258	.227	1.485	420	215	1.134	.453	1.587
"	151		29000	470	3550	410	27.8	1.229	.224	1.451	470	160	1.242	.371	1.613
"	152		28000	486	3600	419	32	1.269	.233	1.502	440	226.2	1.127	.493	1.62
"	153		28400	449	3600	410	39.5	1.292	.232	1.524	422	225	.9883	.502	1.49

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	SEC DRAIN PR-PSIG	LEAKAGE LB/SEC PRI	SEC	TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	SEC DRAIN PR-PSIG	LEAKAGE LB/SEC PRI	SEC	TOTAL
12	153	2.5	28400	449	3600	410	39.5	1.292	.232	1.524	422	225	.9883	.502	1.49
•	154	↓	28250	494	3610	409.5	38.5	1.271	.232	1.503	415	230	.9638	.504	1.468
•	155	↓	28900	482.5	3690	421	38	1.266	.229	1.495	405	214.5	1.005	.471	1.476
•	156	↓	28000	421.5	3550	419	39	1.298	.236	1.534	425	227.5	1.083	.505	1.588
•	157	↓	29000	489	3575	410	35	1.263	.221	1.484	420	201.2	1.032	.499	1.530
•	158	2.4	29000	549	3590	426	32.5	1.278	.2271	1.505	445	185	1.192	.4144	1.606
13	159	-	0	80	500	60	2	.283	.097	.380	36	10	.290	.069	.358
•	•	-	0	70	1000	13.0	6	.559	.118	.677	70	35	.590	.125	.715
•	•	-	0	60	1500	208.5	14	.894	.157	1.051	110	63.7	.907	.200	1.107
•	•	-	0	61	2000	270	22.5	1.175	.207	1.382	142	88.7	1.179	.274	1.453
•	•	-	0	67.5	2400	322.5	30.5	1.1723	.255	1.978	171	108	1.752	.397	2.149
•	•	-	0	80	2800	371	36	1.599	.283	1.882	200	130	1.642	.373	2.015
•	159	2.5	29000	375	3290	390	28	1.269	.211	1.480	420	109	1.340	.261	1.601
•	160	1.3	29000	500	3475	386	26	1.158	.203	1.361	420	110	1.299	.253	1.552
•	161	2.5	29000	500	3300	371	24	1.163	.195	1.358	410	105	1.263	.245	1.508
•	162	2.5	28900	470	3600	332	28	1.238	.216	1.454	405	119	1.292	.289	1.581
•	163	2.5	29000	500	3700	419	28	1.271	.234	1.505	455	129	1.387	.300	1.687
•	164	2.5	29000	500	3590	400	28	1.200	.218	1.418	438	127	1.303	.281	1.584
•	165	2.5	29000	500	3525	395	27.8	1.244	.217	1.461	430	123	1.316	.280	1.596
•	166	2.5	29000	424	3600	396	30	1.309	.229	1.538	423	112	1.377	.270	1.647
•	167	2.5	29000	500	3600	415	26.8	1.283	.214	1.497	458	112	1.365	.248	1.613
•	168	2.5	28400	471	3665	405	29.8	1.280	.229	1.509	425	126	1.348	.291	1.639
•	169	2.5	29000	477	3650	410	28.8	1.280	.228	1.508	440	126	1.382	.291	1.673
•	170	2.5	27000	500	3625	400	30.8	1.269	.229	1.498	432	127	1.334	.299	1.633
•	171	2.5	29000	500	3600	392	30	1.269	.223	1.492	419	124	1.305	.293	1.598
•	172	2.5	28500	490	3575	390	28	1.260	.217	1.477	430	123	1.399	.291	1.600

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	PUMP END SEAL SEC DRAIN PR-PSIG	PUMP END SEAL LEAKAGE LB/SEC PRI	PUMP END SEAL LEAKAGE LB/SEC SEC	PUMP END SEAL LEAKAGE LB/SEC TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	TURBINE END SEAL SEC DRAIN PR-PSIG	TURBINE END SEAL LEAKAGE LB/SEC PRI	TURBINE END SEAL LEAKAGE LB/SEC SEC	TURBINE END SEAL LEAKAGE LB/SEC TOTAL
13	173	2.5	27000	500	3500	392	27	1.281	.216	1.497	438	122	1.322	.287	1.609
"	174	2.5	28750	490	3600	392	26.5	1.275	.218	1.493	430	120	1.308	.278	1.586
"	175	2.5	28500	495	3650	400	28.2	1.294	.227	1.521	445	130	1.351	.309	1.660
"	176	2.5	27500	460	3590	400	29.8	1.322	.223	1.545	449	134	1.352	.316	1.668
"	177	2.5	28250	491	3650	400	29.9	1.310	.221	1.531	458	140	1.342	.323	1.665
"	178	2.5	28400	455	3660	399	29.2	1.336	.224	1.560	450	143	1.378	.336	1.714
"	179	2.5	29000	500	3600	429	26	1.333	.219	1.552	470	128	1.393	.286	1.679
"	180	2.5	28500	480	3550	405	29.5	1.315	.229	1.544	442	145	1.383	.337	1.720
"	181	2.5	29000	487	3600	410	28	1.324	.226	1.550	460	145	1.420	.333	1.753
"	182	2.5	28200	475	3525	400	28	1.327	.221	1.548	4[illegible]	147	1.323	.350	1.673
"	183	2.5	29000	500	3400	409	26	1.313	.212	1.525	465	138	1.339	.307	1.646
"	184	2.5	28750	500	3650	385	28.2	1.292	.218	1.510	460	165	1.362	.401	1.763
"	185	2.5	29000	490	3525	400	26	1.306	.217	1.523	460	192	1.377	.382	1.759
"	186	2.5	28100	462	3400	386	27.8	1.353	.221	1.574	410	165	1.336	.396	1.732
"	187	2.5	29000	453	3275	370	27.2	1.250	.225	1.475	410	160	1.273	.371	1.6[illegible]
"	188	2.5	29000	495	3400	411	28	1.279	.214	1.493	458	162	1.358	.360	1.718
"	189	2.5	26900	500	3500	380	28	1.290	.221	1.511	412	175	1.294	.391	1.685
"	190	2.5	29000	500	3500	416	26	1.322	.212	1.534	456	170	1.369	.357	1.726
"	191	2.5	29000	500	3400	412	27.5	1.315	.216	1.531	460	175	1.344	.388	1.732
"	192	2.5	29000	500	3400	410	28	1.326	.222	1.548	455	178	1.396	.394	1.790
"	193	2.5	29000	500	3300	407	27.5	1.299	.215	1.514	455	165	1.359	.362	1.721
"	194	2.5	29000	500	3450	410	28	1.336	.222	1.558	462	185	-	.409	-
"	195	2.5	29000	500	3200	402	26.5	1.273	.211	1.484	438	164	1.328	.356	1.684
"	196	2.5	28800	500	3290	400	26	1.284	.213	1.497	440	175	1.305	.383	1.688
"	197	2.5	28500	495	3400	405	31	1.331	.226	1.557	460	190	1.384	.426	1.810
"	198	2.5	29000	500	3490	411	29.5	1.319	.221	1.540	457	190	1.369	.413	1.782

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	PUMP END SEAL SEC DRAIN PR-PSIG	PUMP END SEAL LEAKAGE LB/SEC PRI	PUMP END SEAL LEAKAGE LB/SEC SEC	PUMP END SEAL LEAKAGE LB/SEC TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	TURBINE END SEAL SEC DRAIN PR-PSIG	TURBINE END SEAL LEAKAGE LB/SEC PRI	TURBINE END SEAL LEAKAGE LB/SEC SEC	TURBINE END SEAL LEAKAGE LB/SEC TOTAL
13	199	2.5	30000	500	3470	412	29.9	1.329	.219	1.548	458	189	1.365	.410	1.775
"	200	2.5	29000	500	3500	419	31.2	1.320	.226	1.546	457	196	1.366	.437	1.803
"	201	2.5	29000	500	3500	410	27.5	1.306	.220	1.526	450	185	1.348	.404	1.752
"	202	2.5	29000	445	3325	399	28	1.321	.217	1.538	439	191	1.364	.432	1.796
"	203	2.5	29800	499	3400	414	28	1.323	.222	1.545	456	195	1.354	.423	1.777
"	204	2.5	28000	490	3325	377	27.8	1.228	.220	1.448	437	195	1.324	.427	1.751
"	205	2.5	29000	500	3450	420	28.3	1.319	.226	1.545	460	195	1.396	.445	1.841
"	206	2.5	29000	500	3350	410	27.8	1.287	.218	1.505	455	190	1.388	.395	1.783
"	207	2.5	29000	470	3525	407	30	1.341	.228	1.569	455	213	1.410	.467	1.877
"	208	2.5	29000	500	3400	409	28	1.312	.226	1.538	450	209	1.346	.442	1.788
"	209	2.5	29500	500	3425	411	28.5	1.310	0.217	1.527	455	210	1.346	.449	1.795
"	210	2.5	29000	500	3425	409	28	1.298	.215	1.513	448	207	1.346	.441	1.787
"	211	2.5	29500	500	3450	411	28	1.308	.220	1.528	460	209	1.346	.446	1.792
"	212	2.5	29000	498	3350	400	26.2	1.287	.213	1.500	440	198	1.305	.435	1.740
"	213	2.5	29000	500	3400	415	28.3	1.353	.230	1.583	460	219	1.349	.468	1.817
"	214	2.5	29000	500	3250	392	28.5	1.312	.231	1.543	430	205	1.307	.481	1.788
"	215	2.5	29000	500	3400	414	29	1.328	.228	1.556	451	215	1.349	.452	1.801
"	216	2.5	29500	500	3425	415	30	1.331	.231	1.562	450	214	1.354	.461	1.815
"	217	2.5	29000	500	3350	415	29.8	1.333	.226	1.559	452	205	1.347	.460	1.807
"	218	2.5	29000	500	3375	410	28	1.323	.226	1.549	445	215	1.346	.484	1.830
14	PRE 219	-	0	201	500	60	4	0.264	0.104	0.368	72	8	0.271	0.279	0.55
"	"	-	0	198	1000	147.5	10.5	0.555	0.135	0.690	160	25	0.592	0.604	1.196
"	"	-	0	160	1500	225	20	0.815	0.186	1.001	240	45	0.871	0.872	1.743
"	"	-	0	110	2000	291.5	30.2	1.173	0.239	1.412	322	67.5	1.239	1.217	2.456
"	"	-	0	70	2210	325	34.2	1.383	0.252	1.635	358	80.0	1.436	1.406	2.842
"	219	2.5	27000	500	3300	415	28	1.2405	0.226	1.4665	443	97.5	1.2602	0.4539	1.714

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	PUMP END SEAL SEC DRAIN PR-PSIG	PUMP END SEAL LEAKAGE LB/SEC PRI	PUMP END SEAL LEAKAGE LB/SEC SEC	PUMP END SEAL LEAKAGE LB/SEC TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	TURBINE END SEAL SEC DRAIN PR-PSIG	TURBINE END SEAL LEAKAGE LB/SEC PRI	TURBINE END SEAL LEAKAGE LB/SEC SEC	TURBINE END SEAL LEAKAGE LB/SEC TOTAL
14	220	2.5	26000	439	3400	431	34	1.3557	0.2488	1.6045	450	105	1.4078	0.5024	1.9102
"	221	2.5	27000	488.5	3400	430	30	1.3517	0.2577	1.6094	460	105	1.3709	0.5109	1.8818
"	222	2.5	28000	486	3500	422.5	30.5	1.3206	0.2477	1.5683	448	112.5	1.3172	0.5262	1.8434
"	223	2.5	29000	500	3400	415	30	1.3113	0.2426	1.5539	438	105.5	1.2584	0.5120	1.7704
"	224	2.5	29000	450	3450	420	27	1.3522	0.2513	1.6035	445	112	1.3824	0.5407	1.9231
"	225	2.5	29000	500	3425	415	26.5	1.2958	0.2298	1.5256	439	120	1.2532	0.5338	1.7870
"	226	2.5	29000	493	3525	416	30	1.3394	0.2314	1.5708	431	154.5	1.1746	0.6941	1.8687
"	227	2.5	29000	500	3415	429	30.2	1.3163	0.2296	1.5459	410	140.75	1.1911	0.6149	1.8060
"	228	2.5	29000	440	3400	402.5	30	1.3388	0.2372	1.5760	343	148.75	1.1531	0.7045	1.8576
"	229	2.5	29000	434	3425	409	31.8	1.3461	0.2406	1.5867	322	190	0.9698	0.8795	1.8493
"	230	2.5	29000	499	3490	410	35	1.3064	0.2428	1.5489	350	179.5	1.0330	0.7988	1.8318
"	231	2.5	29000	500	3200	397.5	29.5	1.2273	0.2267	1.4540	282	184.5	0.8851	0.7929	1.6780
"	232	2.5	29000	485	3430	411.5	30.3	1.3055	0.2436	1.5491	320	185	0.8873	0.8452	1.7325
"	233	2.5	29000	477.5	3500	440	38	1.3568	0.2579	1.6147	263	225	0.8235	1.015	1.8385
"	234	2.5	29000	490	3530	430	34	1.3633	0.2516	1.6149	290	222	0.8468	0.9807	1.8275
"	235	2.5	29000	500	3500	424	34	1.3243	0.2447	1.5690	350	197.5	0.9317	0.8621	1.7938
"	236	2.5	29000	500	3420	419	31.5	1.3075	0.2345	1.5420	320	202.5	0.8825	0.8699	1.7524
"	237	2.5	29000	477.5	[illegible]	417.5	31	1.3172	0.2293	1.5465	320	207.5	0.8358	0.9293	1.7657
"	238	2.5	29000	490	3500	435	36	1.3386	0.2543	1.5929	319	203.5	0.8878	0.9320	1.8198
"	239	2.5	29000	500	3425	414	31.6	1.2862	0.2302	1.5164	345	190	0.9397	0.8698	1.8095
"	240	2.5	29000	479	3450	[illegible]	32.5	1.3172	0.2394	1.5566	360	189.5	0.9895	0.8490	1.8385
"	241	2.5	29000	460	3500	422.5	34	1.3293	0.2423	1.5716	320	210	0.8672	0.9258	1.7930
"	242	2.5	29000	481	3500	415	34	1.3420	0.2467	1.5887	321	185.75	0.9452	0.8438	1.7890
"	243	2.5	29000	500	3400	410	31	1.2894	0.2284	1.5178	342	184.5	0.9256	0.8072	1.7328
"	244	2.5	29000	500	3475	425	31	1.3129	0.2263	1.5392	280	240	0.7578	1.0461	1.8039
"	245	2.5	29000	500	3400	400	30	1.2796	0.2182	1.4978	325	201.25	0.8646	0.8780	1.7426

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	SEC DRAIN PR-PSIG	LEAKAGE LB/SEC PRI	SEC	TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	SEC DRAIN PR-PSIG	LEAKAGE LB/SEC PRI	SEC	TOTAL
14	246	2.5	29000	500	3390	410	29.8	1.2780	0.2245	1.5025	280	220	0.7845	0.9500	1.7345
"	247	2.5	29000	500	3450	415	32	1.3099	0.2273	1.5372	255	230	0.7698	1.0075	1.7773
"	248	2.5	29000	489	3400	410	31	1.3201	0.2220	1.5421	345	192.5	0.9421	0.8832	1.8253
"	249	2.5	26000	489	3400	410	33.8	1.3168	0.2466	1.5634	240	214.5	0.7966	0.9700	1.7666
"	250	2.5	29000	482	3450	410	31	1.2770	0.2182	1.4952	270	211.25	0.8036	0.9388	1.7424
"	251	2.5	29000	500	3325	420	30.8	1.2788	0.2239	1.5027	318	207.5	0.8578	0.8866	1.7444
"	252	2.5	29000	500	3200	406	28	1.2216	0.2119	1.4335	301	195	0.8578	0.8243	1.6821
"	253	2.5	29000	450	3300	411	31	1.3199	0.2245	1.5444	324	204.5	0.9222	0.9024	1.8246
"	254	2.5	29000	500	3475	425	32	1.3026	0.2239	1.5265	322	210	0.8754	0.8833	1.7587
"	255	2.5	29000	500	3350	429	33	1.2932	0.2369	1.5301	299	209.5	0.8744	0.9178	1.7922
"	256	2.5	29000	500	3400	429	33.5	1.3305	0.2295	1.5600	318	215	0.8724	0.9268	1.7992
"	257	2.5	29000	470	3450	420	34	1.3095	0.2399	1.5494	260	212.5	0.8751	0.9009	1.7760
"	258	2.5	29000	488	3600	410	32	1.2904	0.2384	1.5288	320	228	0.8230	1.009	1.8320
"	259	2.5	29000	500	3475	435	35.3	1.3298	0.2379	1.5677	297	220	0.8371	0.9771	1.8142
"	260	2.5	29000	500	3440	416.5	31	1.3017	0.2328	1.5345	299	225	0.8436	0.8535	1.6971
"	261	2.5	29000	489	3450	432.5	33	1.3298	0.2453	1.5951	300	223	0.8440	0.9921	1.8361
"	262	2.5	29000	500	3430	430	33.7	1.3190	0.2498	1.5688	310	218	0.8637	1.0720	1.9357
"	263	2.5	29000	477	3400	435	35	1.3266	0.2412	1.5678	306	215.5	0.8388	0.9606	1.7994
"	264	2.5	29000	491	3500	419	35	1.3401	0.2499	1.5900	318	212.5	0.8879	0.9629	1.8508
"	265	2.5	29000	500	3425	440	32	1.2960	0.2374	1.5334	319	212.5	0.8531	0.9030	1.7561
"	266	2.5	29000	496	3400	442.5	33	1.2870	0.2316	1.5186	307	215.5	0.8346	0.9408	1.7754
"	267	2.5	29000	459	3400	430	35.5	1.3313	0.2492	1.5805	320	215.5	0.9012	0.9694	1.8706
"	268	2.5	29000	500	3450	431	34	1.2796	0.2375	1.5171	310	210	0.8737	0.9067	1.7801
"	269	2.5	29000	448	3300	425	33.8	1.2844	0.2333	1.5177	298	210	0.8512	0.9577	1.8089
"	270	2.5	29000	499	3400	425	33.2	1.2679	0.2280	1.4959	300	210	0.8443	0.8981	1.7424
"	271	2.5	29000	492	3450	420	34.8	1.3313	0.2457	1.5770	305	199.5	0.8511	0.9035	1.7546

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL					TURBINE END SEAL				
						PRI DRAIN PR-PSIG	SEC DRAIN PR-PSIG	LEAKAGE LB/SEC			PRI DRAIN PR-PSIG	SEC DRAIN PR-PSIG	LEAKAGE LB/SEC		
								PRI	SEC	TOTAL			PRI	SEC	TOTAL
14	272	2.5	29000	500	3475	440	32.3	1.3395	.2377	1.5772	320	212.5	.8223	0.9257	1.7480
"	273	2.5	29000	489	3400	441	33.3	1.3939	.2536	1.6475	320	210	.9372	0.9658	1.9030
"	274	2.5	29000	500	3410	442.5	34.8	1.3436	.2444	1.5880	320	209.5	.8790	0.9289	1.8079
"	275	2.5	29000	500	3400	432.5	32	1.3025	.2315	1.5340	320	200	.9123	0.8550	1.7673
"	276	2.5	29000	497	3425	435	32.8	1.3291	.2347	1.5638	320	205.5	.9240	0.8904	1.8144
"	277	2.5	29000	491	3440	435	32.2	1.3183	.2375	1.5558	317	209.5	.8587	0.9399	1.7986
"	278	2.5	29000	500	3450	440	36	1.3512	.2523	1.6035	301	215.5	.8834	0.9787	1.8621
15	279	2.5	29000	489	3350	67.5	28.0	1.278	.2180	1.496	325	166.3	.9767	0.7762	1.753
"	280	2.5	29800	491	3590	216.5	32.0	1.339	.2418	1.581	320	202.5	.7958	.8832	1.679
"	281	2.5	29000	500	3520	350.0	30.5	1.382	.2278	1.610	358	185.5	1.004	.8133	1.817
"	282	2.5	29000	500	3435	351.0	30.0	1.356	.2224	1.578	338	207.5	.8718	.8692	1.741
"	283	2.5	29000	500	3480	320.0	30.3	1.356	.2273	1.583	358	180.0	.9355	.7979	1.733
"	284	2.5	29000	491	3500	295.0	32.0	1.372	.2312	1.603	355	188.3	.9697	.8470	1.817
"	285	2.5	29000	500	3500	330.0	29.9	1.347	.2165	1.564	365	185.0	.9622	.8116	1.774
"	286	2.5	29000	475	3475	261.0	31.8	1.339	.2300	1.569	310	209.5	.8359	.9360	1.772
"	287	2.5	29000	500	3500	341.5	30.0	1.334	.2208	1.555	340	219.5	.9151	.8476	1.763
"	288	2.5	29000	441.5	3400	345.0	32.0	1.361	.2345	1.596	225	235.0	.7698	1.0545	1.824
"	289	2.5	29000	431.5	3450	281.5	30.5	1.363	.2352	1.598	200	250.0	.6800	1.1420	1.822
"	290	2.5	29000	500	3450	330.0	29.8	1.318	.2294	1.547	335	195.0	.8749	.8456	1.721
"	291	2.5	29000	500	3330	340.0	30.0	1.292	.2256	1.518	200	250.0	.9101	1.072	1.982
"	292	2.5	29000	500	3500	279.5	34.0	1.317	.2491	1.566	210	255.0	.9209	1.125	2.046
"	293	2.5	29000	500	3520	252.0	32.1	1.331	.2455	1.577	340	199.0	.8867	.9010	1.788
"	294	2.5	29000	500	3450	329.0	31.0	1.305	.2285	1.534	220	240.0	.9541	1.037	1.992
"	295	2.5	29000	500	3250	336.5	28.5	1.214	.2159	1.430	263	222.5	.6542	.9442	1.598
"	296	2.5	29000	480	3500	245.0	31.0	1.274	.2320	1.506	280	232.5	.6473	1.045	1.692
"	297	1.25	29000	500	3400	341.0	31.0	1.280	.2249	1.505	230	249.0	.6396	1.076	1.716

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	PUMP END SEAL SEC DRAIN PR-PSIG	PUMP END SEAL LEAKAGE LB/SEC PRI	PUMP END SEAL LEAKAGE LB/SEC SEC	PUMP END SEAL LEAKAGE LB/SEC TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	TURBINE END SEAL SEC DRAIN PR-PSIG	TURBINE END SEAL LEAKAGE LB/SEC PRI	TURBINE END SEAL LEAKAGE LB/SEC SEC	TURBINE END SEAL LEAKAGE LB/SEC TOTAL
16	298	2.5	29000	496	3775	165	34.2	1.351	.2608	1.612	220	40.0	1.234	.2448	1.479
"	299	2.5	29000	500	3700	400	31.0	1.341	.2329	1.574	225	40.0	1.260	.2307	1.490
"	300	2.5	29000	500	3800	370	30.0	1.371	.2337	1.605	230	42.5	1.318	.2668	1.585
"	301	2.5	29000	500	3675	145	39.5	1.372	.2622	1.634	232	45.0	1.343	.2374	1.580
"	PRE 302	-	0	180	400	40	0.8	1.199	0.087	0.286	39	2.5	.2012	0.081	0.282
"	"	-	0	170	1000	111.5	4.2	0.527	0.105	0.632	80	5.0	.5348	0.085	0.620
16	PRE 302	-	0	145	1500	170	10.0	0.812	0.126	0.938	120	13.8	.8231	0.114	0.937
"	"	-	0	95	2000	245	18.0	1.115	.1577	1.273	150	25.0	1.179	0.181	1.360
"	"	-	0	70	2500	312.5	28.0	1.503	.2261	1.729	200	37.5	1.572	.2525	1.825
"	302	2.5	29000	500	3800	405	32.0	1.373	.2117	1.585	240	40.0	1.336	.2072	1.543
"	303	2.5	29000	500	3800	405	32.0	1.341	.2179	1.559	235	43.3	1.330	.2112	1.541
"	304	2.5	29000	500	3700	415	31.5	1.361	.2140	1.575	240	37.5	1.339	.1904	1.529
"	305	2.5	29000	500	3700	392.5	32.0	1.341	.2177	1.559	240	37.5	1.352	.2044	1.556
"	306	2.5	29000	500	3600	335	30.0	1.269	.2051	1.474	228	39.5	1.308	.2086	1.517
"	307	2.5	29000	500	3680	369	31.0	1.329	.2108	1.540	235	37.5	1.336	.1960	1.532.
"	308	2.5	29000	500	3500	398	28.4	1.293	.1973	1.490	230	33.0	1.311	.1775	1.489
"	309	2.5	29000	473.5	3600	275	33.8	1.349	.2298	1.579	222	43.3	1.352	.2416	1.594
"	310	2.5	29000	500	3800	331	33.8	1.387	.2349	1.622	238	35.5	1.372	.2137	1.586
"	311	2.5	29000	500	3700	360	30.0	1.325	.2140	1.539	240	35.0	1.353	.1797	1.533
"	312	2.5	29000	500	3700	339	32.0	1.346	.2201	1.566	240	35.8	1.367	.2019	1.569
"	313	2.5	29000	500	3750	295	33.0	1.378	.2340	1.612	240	40.3	1.373	.2240	1.597
"	314	2.5	29000	500	3700	340	29.9	1.326	.2141	1.540	238	35.0	1.353	.1921	1.545
"	315	2.5	29000	500	3600	400	27.5	1.313	.2004	1.513	240	32.0	1.286	.1753	1.461
"	316	2.5	29000	500	3700	285	32.0	1.375	.2255	1.601	238	40.0	1.299	.2364	1.535
"	317	2.5	29000	500	3700	394	30.0	1.336	.2094	1.545	240	33.3	1.299	.1915	1.491
"	318	2.5	29000	500	3600	365	18.0	1.309	.2013	1.510	230	35.0	1.227	.2029	1.430

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	PUMP END SEAL SEC DRAIN PR-PSIG	PUMP END SEAL LEAKAGE LB/SEC PRI	PUMP END SEAL LEAKAGE LB/SEC SEC	PUMP END SEAL LEAKAGE LB/SEC TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	TURBINE END SEAL SEC DRAIN PR-PSIG	TURBINE END SEAL LEAKAGE LB/SEC PRI	TURBINE END SEAL LEAKAGE LB/SEC SEC	TURBINE END SEAL LEAKAGE LB/SEC TOTAL
"	319	2.5	29000	500	3700	345	29.0	1.347	.2132	1.560	240	39.5	1.271	.2246	1.496
"	320	2.5	29000	500	3700	360	28.0	1.323	.2007	1.524	230	36.5	1.250	.2052	1.455
"	321	2.5	29000	492	3675	252	30.0	1.326	.2149	1.541	220	40.0	1.228	.2241	1.452
"	322	2.5	29000	500	3700	340	34.0	1.310	.1986	1.509	220	30.5	1.260	.1831	1.443
"	323	2.5	29000	480	3700	255	33.8	1.382	.2421	1.624	222	42.5	1.370	.2467	1.617
16	324	2.5	29000	494	3625	271	31.5	1.341	.2296	1.571	223	40.5	1.328	.2406	1.569
"	325	2.5	29000	270	3700	242.5	32.0	1.390	.2413	1.631	230	45.5	1.362	.2577	1.620
"	326	2.5	29000	500	3650	284	29.0	1.346	.2286	1.575	230	44.5	1.318	.2359	1.554
"	327	2.5	29000	500	3650	419	36.5	1.348	.2063	1.554	240	37.5	1.339	.1834	1.522
"	328	2.5	29000	500+	3700	355	29.0	1.364	.2131	1.577	230	45.0	1.349	.2326	1.582
"	329	2.5	29000	500	3700	331	28.4	1.351	.2146	1.566	224	47.5	1.332	.2475	1.580
"	330	2.5	29000	500	3700	320	28.6	1.360	.2168	1.577	225	47.0	1.330	.2495	1.580
"	331	2.5	29000	500	3750	329.5	28.0	1.364	.2149	1.579	230	48.8	1.325	.2521	1.577
"	332	2.5	29000	497	3700	260	29.8	1.324	.2183	1.542	220	50.0	1.290	.2650	1.555
"	333	2.5	29000	500+	3750	281.5	29.0	1.361	.2110	1.572	220	51.0	1.304	.2616	1.566
"	334	2.5	29000	500+	3725	369.5	22.0	1.371	.1958	1.568	220	45.0	1.303	.2366	1.540
"	335	2.5	29000	489.5	3725	207.5	29.2	1.415	.2235	1.639	230	53.3	1.398	.2801	1.678
"	336	2.5	29000	495	3700	255	30.7	1.386	.2275	1.614	228	50.0	1.370	.2551	1.625
"	337	2.5	29000	480	3680	320	36.5	1.404	.2180	1.622	225	51.0	1.366	.2611	1.627
"	338	2.5	29000	500+	3600	326	34.0	1.333	.1917	1.525	220	45.0	1.316	.2276	1.544
"	339	2.5	29000	459	3650	245	29.95	1.398	.2272	1.625	220	54.5	1.366	.2659	1.632
"	340	2.5	29000	500+	3600	410	25.0	1.342	.1937	1.536	220	45.5	1.306	.2212	1.527
"	341	2.5	29000	500+	3650	369	26.0	1.371	.2006	1.572	220	50.0	1.362	.2561	1.618
"	342	2.5	29000	500+	3600	325	24.0	1.335	.1971	1.532	220	47.5	1.349	.2551	1.604
"	343	2.5	29000	460	3650	277.5	28.0	1.408	.2160	1.624	220	50.0	1.392	.2910	1.683
"	344	2.5	29000	500+	3750	315	20.0	1.196	.1709	1.367	198	35.0	1.195	.2234	1.418

(+) INSTRUMENTATION PEGGED

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	PUMP END SEAL SEC DRAIN PR-PSIG	PUMP END SEAL LEAKAGE LB/SEC PRI	PUMP END SEAL LEAKAGE LB/SEC SEC	PUMP END SEAL LEAKAGE LB/SEC TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	TURBINE END SEAL SEC DRAIN PR-PSIG	TURBINE END SEAL LEAKAGE LB/SEC PRI	TURBINE END SEAL LEAKAGE LB/SEC SEC	TURBINE END SEAL LEAKAGE LB/SEC TOTAL
"	345	2.5	29000	500+	3600	389	24.2	1.341	.1965	1.538	220	43.0	1.342	.2441	1.586
"	346	2.5	29000	500+	3650	367.5	23.9	1.355	.1905	1.546	220	43.8	1.346	.2533	1.599
"	347	2.5	29000	500	3775	341	24.0	1.372	.2057	1.578	220	48.8	1.271	.2507	1.522
"	348	2.5	2900	500+	3600	367.5	28.0	1.367	.2169	1.584	240	55.0	1.343	.2584	1.601
16	349	2.5	29000	490	3580	428	30.0	1.373	.2385	1.612	237	55.0	1.287	.2704	1.557
"	350	2.5	29000	482.5	3500	425	29.0	1.328	.2285	1.557	225	52.0	1.325	.2767	1.602
"	351	2.5	29000	492	3600	402	31.2	1.339	.2425	1.582	222	55.0	1.351	.2796	1.631
"	352	2.5	29000	474	3500	417	28.8	1.313	.2178	1.531	222	55.0	1.325	.2733	1.598
"	353	2.5	29000	500+	3500	418	26.5	1.268	.2121	1.480	230	50.0	1.331	.2403	1.571
"	354	2.5	29000	482.5	3610	413	31.5	1.362	.2288	1.591	230	59.5	1.407	.2891	1.696
"	355	2.5	29000	500	3500	420	26.2	1.280	.2157	1.496	220	54.5	1.327	.2583	1.585
"	356	2.5	29000	492	3675	418	31.0	1.346	.2383	1.584	238	60.0	1.369	.2891	1.658
"	357	2.5	29000	452	3700	417	31.5	1.374	.2282	1.602	238	35.5	1.392	.2008	1.693
17	358	2.5	29000	490	3500	380	39.8	1.307	0.307	1.614	220	35.5	1.275	0.187	1.462
"	359			500+	3500	388	42	1.287	0.296	1.583	221	35.5	1.249	0.199	1.448
"	360			491	3450	390	46	1.343	0.302	1.645	220	45	1.236	0.267	1.503
"	361			500+	3550	388	44	1.286	0.197	1.583	225	35	1.216	0.201	1.417
"	362			500+	3485	381	43.8	1.311	0.299	1.610	220	40.5	1.215	0.233	1.448
"	363			500+	3510	397	45	1.325	0.306	1.631	220	36.3	1.239	0.211	1.450
"	364			479	3500	390	46	1.350	0.308	1.658	220	40	1.224	0.226	1.450
"	365			500	3500	390	47	1.312	0.306	1.618	222	35	1.190	0.199	1.389
"	366			500	3420	392	48	1.290	0.302	1.592	220	37	1.135	0.211	1.346
"	367			500	3500	379	43	1.269	0.287	1.556	215	36	1.155	0.208	1.363
"	368			500	3400	379	52	1.257	0.294	1.551	220	34	1.197	0.186	1.383
"	369			500	3380	385	52	1.247	0.295	1.542	219	35	1.203	0.203	1.406
"	370			500	3400	382	51	1.265	0.302	1.567	220	36	1.207	0.207	1.414

(+) INSTRUMENTATION PEGGED

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL PRI DRAIN PR-PSIG	PUMP END SEAL SEC DRAIN PR-PSIG	PUMP END SEAL LEAKAGE LB/SEC PRI	PUMP END SEAL LEAKAGE LB/SEC SEC	PUMP END SEAL LEAKAGE LB/SEC TOTAL	TURBINE END SEAL PRI DRAIN PR-PSIG	TURBINE END SEAL SEC DRAIN PR-PSIG	TURBINE END SEAL LEAKAGE LB/SEC PRI	TURBINE END SEAL LEAKAGE LB/SEC SEC	TURBINE END SEAL LEAKAGE LB/SEC TOTAL
17	371	2.5	29000	500	3430	382	46	1.266	0.296	1.562	[illegible]	37	1.196	0.208	1.404
"	372			500	3420	372	50	1.269	0.297	1.566	[illegible]	41	1.200	0.225	1.424
"	373			500	3410	380	44	1.261	0.297	1.558	212	37	1.192	0.208	1.400
"	374			500	3400	375	42	1.267	0.279	1.546	220	39	1.209	0.212	1.421
"	375			500	3320	377	43	1.212	0.288	1.500	225	35	1.213	0.201	1.414
"	376			500	3380	369	44	1.232	0.296	1.528	228	41	1.202	0.235	1.437
"	377			500+	3400	375	43	1.231	0.290	1.521	225	39	1.241	0.224	1.465
"	378			500+	3390	370	43	1.242	0.290	1.532	223	42	1.241	0.234	1.475
"	379			500+	3290	370	43	1.230	0.296	1.526	220	40	1.209	0.239	1.448
"	380			500+	3400	390	42	1.260	0.286	1.546	215	46	[illegible]	0.237	1.408
"	381			500+	3400	382	46	1.272	0.297	1.569	220	50	1.199	0.261	1.460
"	382			500+	3270	390	44	1.219	0.289	1.508	218	40	1.138	0.223	1.361
"	383			500+	3390	390	44	1.258	0.301	1.559	220	45	1.175	0.235	1.41
"	384			500+	3320	385	47	1.250	0.294	1.544	215	41	1.096	0.223	1.319
"	385			500+	3380	391	46	1.257	0.300	1.557	220	44	1.089	0.234	1.323
"	386			500+	3400	391	46	1.258	0.299	1.557	225	46	1.096	0.246	1.342
"	387			500+	3350	385	43	1.253	0.284	1.537	217	45	1.150	0.238	1.388
"	388			500+	3430	385	46	1.285	0.302	1.587	220	50	1.171	0.269	1.440
"	389			500+	3400	382	46	1.284	0.298	1.582	210	[illegible]	[illegible]	0.272	1.439
"	390			500+	3390	382	45	1.262	0.297	1.559	220	46	[illegible]	0.253	1.395
"	391			500+	3330	385	44	1.225	0.294	1.519	220	46	[illegible]	[illegible]	[illegible]
"	392			500+	3350	390	46	1.256	0.296	1.552	220	45	[illegible]	0.253	1.394
"	393			500+	3420	380	45	1.284	0.297	1.581	217	51	[illegible]	0.284	1.419
"	394			495	3400	390	46	1.274	0.309	1.583	200	48	1.141	0.267	1.408
"	395			500+	3330	383	46	1.245	0.300	1.545	220	45	1.134	0.243	1.377
"	396			488	3550	390	43	1.285	0.300	1.585	200	49	1.078	0.272	1.350
"	397			500	3500	395	44.5	1.278	0.309	1.587	215	55	1.104	0.285	1.389
"	398			498	3550	392	44.2	1.288	0.309	1.597	210	57	1.110	0.287	1.397

(+) INSTRUMENTATION PEGGED

TABLE 12. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL					TURBINE END SEAL				
						PRI DRAIN PR-PSIG	SEC DRAIN PR-PSIG	LEAKAGE LB/SEC			PRI DRAIN PR-PSIG	SEC DRAIN PR-PSIG	LEAKAGE LB/SEC		
								PRI	SEC	TOTAL			PRI	SEC	TOTAL
17	399	2.5	29000	500+	3500	388	43.5	1.259	0.299	1.558	218	57	1.098	0.281	1.379
"	400	2.5	29000	500+	400	390	46	1.240	0.297	1.537	220	52	1.095	0.264	1.259
"	401	2.5	29000	500	00	380	45	1.196	0.273	1.469	220	52	1.191	0.260	1.451
"	402	2.5	29000	500	00	370	44	1.180	0.265	1.445	218	50	1.175	0.248	1.423
"	403	2.5	29000	500+	3250	370	45	1.198	0.269	1.467	215	55	1.170	0.270	1.440
"	404	2.5	29000	500	3200	377	44	1.202	0.270	1.472	220	54	1.151	0.262	1.413
"	405	2.5	29000	500+	3400	380	46	1.274	0.287	1.561	220	64	1.188	0.303	1.491
"	406	2.5	29000	490	3475	383	48.2	1.320	0.302	1.622	220	68	1.183	0.339	1.522
"	407	2.5	29000	500+	3400	379	46	1.280	0.292	1.572	220	67	1.200	0.323	1.523
"	408	2.51	29000	500+	3400	375	45.5	1.281	0.284	1.565	220	67	1.226	0.322	1.548
"	409	2.5	29000	500+	3250	370	46.2	1.203	0.276	1.479	220	53	1.197	0.270	1.467
"	410	2.5	29000	500+	3275	372	45	1.221	0.275	1.496	218	63	1.184	0.298	1.482
"	411	2.5	29000	500+	3300	379	48	1.223	0.279	1.502	220	57	1.234	0.271	1.505
"	412	2.5	29000	495	3500	370	45.9	1.275	0.300	1.575	154	67	1.158	0.332	1.490
"	413	2.5	29000	500+	3150	367	42.8	1.152	0.263	1.415	210	50	1.078	0.221	1.299
"	414	2.5	29000	500+	3100	360	42	1.161	0.269	1.430	218	55	1.128	0.269	1.397
"	415	2.5	29000	500+	3250	371	45.8	1.207	0.281	1.488	220	55	1.091	0.272	1.363
"	416	2.5	29000	500+	3325	378	45.5	1.226	0.286	1.512	220	65	1.092	0.309	1.401
"	417	2.5	29000	500+	3225	370	46	1.184	0.276	1.560	220	58	1.083	0.266	1.349
18	418	2.5	29000	500+	3225	378	44.2	1.217	0.2797	1.4967	200	63	1.101	0.328	1.429
"	419	2.5	29000	500+	3300	350	46	1.240	0.2935	1.5335	200	63	1.060	0.308	1.368
"	420	2.5	29000	500+	3200	368	44	1.223	0.2856	1.5086	200	66	1.115	0.334	1.449
"	421	2.5	29000	500+	3100	370	46.2	1.186	0.2926	1.4786	210	55	1.117	0.275	1.392
19	422	2.5	29000	500+	3300	395	42	1.265	0.4802	1.7452	208	72	1.143	0.319	1.462
"	423	2.5	29000	500+	3225	391	43	1.262	0.4939	1.7559	210	62	1.118	0.296	1.414
"	424	2.5	29000	500+	3175	381	42	1.228	0.4809	1.7089	208	70	1.104	0.290	1.394

(+) INSTRUMENTATION PEGGED

TABLE 12. (Concluded)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RPM	INLET TEMP F	INLET PR. PSIG	PUMP END SEAL					TURBINE END SEAL				
						PRI DRAIN PR-PSIG	SEC DRAIN PR-PSIG	LEAKAGE LB/SEC			PRI DRAIN PR-PSIG	SEC DRAIN PR-PSIG	LEAKAGE LB/SEC		
								PRI	SEC	TOTAL			PRI	SEC	TOTAL
19	425	2.5	29000	500+	3325	426	46	1.297	0.2910	1.588	220	65	1.177	0.301	1.478
"	426			495	3400	400	46	1.345	0.3061	1.651	215	72	1.176	0.365	1.541
"	427			500+	3250	400	45.8	1.279	0.2949	1.574	220	60	1.174	0.306	1.480
"	428			440	3325	390	45	1.351	0.3066	1.6576	205	72	1.189	0.380	1.5690
"	429			500+	3290	389	44	1.286	0.2890	1.5750	210	64	1.153	0.330	1.483
"	430			500+	3250	398	46	1.285	0.2966	1.5816	217	62	1.146	0.327	1.481
"	433			500+	3300	385	44	1.250	0.2908	1.5408	200	70	1.104	0.324	1.428
"	434			500+	3250	390	44	1.262	0.2932	1.5552	210	62	1.150	0.288	1.438
"	435			500+	3225	382	44	1.258	0.2914	1.5494	200	61	1.106	1.304	1.410
"	436			485	3300	375	44	1.289	0.2942	1.5832	185	65	1.087	0.341	1.428
20	437			455	3325	380	41	*	*	*	190	72	*	*	*
"	438			478	3400	400	40				200	70			
"	439			500+	3250	405	48				200	49			
"	440			500+	3225	393	38				200	45			
"	441			500+	3400	410	39				202	51			
"	442			492	3500	410	38				200	51			
"	443			500+	3200	390	38				185	38			
"	444			488	3500	400	37				198	57			
"	445			500+	3550	400	42				220	53			
"	446			500+	3500	395	40				208	52			
"	447			460	3500	380	42				195	49			
"	448			500+	3400	405	42				215	48			
"	449			500+	3550	385	43				200	49			
"	450			500+	3300	370	39				200	46			
"	451			500	3500	380	39				198	55			
"	452			500+	3500	400	41				200	52			
"	453			485	3500	390	41				210	55			
"	454			500+	3500	415	42				205	53			
"	455			492	3500	400	42				195	50			
"	456			500+	3425	380	42				197	49			
"	457			500+	3350	405	43				205	49			
"	458			500+	3350	400	40				205	49			
"	459			500+	3500	405	42				200	48			
"	460			500+	3400	425	48	1.304	0.3137	1.618	210	61	1.132	0.296	1.428
"	461			492	3500	405	45	1.373	0.3027	1.676	200	70	1.122	0.357	1.479
"	462			500+	3300	410	46	1.313	0.3062	1.619	215	66	1.125	0.327	1.452
"	463			500+	3400	422	48	1.327	0.3182	1.645	218	70	1.153	0.339	1.492
"	464			500+	3325	420	49	1.302	0.3147	1.617	220	66	1.144	0.334	1.478
"	465			500+	3350	430	48	1.309	0.3158	1.625	220	65	1.147	0.330	1.477
"	466			500+	3350	430	46	1.305	0.3057	1.611	220	64	1.146	0.325	1.471
"	467			500+	3400	428	48	1.313	0.3182	1.631	218	65	1.150	0.337	1.487
"	468			500+	3400	438	47	1.313	0.3034	1.616	215	63	1.127	0.329	1.456
"	469			[illegible]	3500	400	44	1.353	0.3035	1.657	205	52	1.111	0.400	1.511
"	470			500+	3500	410	46	1.332	0.3063	1.638	210	68	1.206	0.364	1.570
"	471			500+	3425	400	47	1.331	0.3127	1.644	215	68	1.132	0.342	1.474
"	472			500+	3500	400	49	1.341	0.3242	1.665	218	70	1.143	0.358	1.501
"	473			500+	3400	410	48	1.302	0.3158	1.618	220	71	1.134	0.331	1.465
"	474			500+	3500	415	48	1.335	0.3148	1.650	220	68	1.153	0.355	1.508
"	475			500+	3500	420	48	1.323	0.3206	1.644	220	67	1.150	0.339	1.489
"	476			500+	3450	430	48	1.319	0.3182	1.637	220	66	1.147	0.332	1.479
"	477			500+	3400	420	46	1.305	0.3125	1.618	218	65	1.119	0.327	1.446

*INSTRUMENTATION PROBLEM - INVALIDATED DATA
(+)INSTRUMENTATION PEGGED

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OF POOR QUALITY

TABLE 13. HOT-GAS TURBINE SEAL DATA SUMMARY - SI UNITS

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M²	PUMP END SEAL: PR DRAIN N/M²	PUMP END SEAL: SEC DRAIN N/M²	PUMP END SEAL: LEAKAGE KG/SEC PRI	PUMP END SEAL: LEAKAGE KG/SEC SEC	PUMP END SEAL: LEAKAGE KG/SEC TOTAL	TURBINE END SEAL: PRI DRAIN N/M²	TURBINE END SEAL: SEC DRAIN N/M²	TURBINE END SEAL: LEAKAGE KG/SEC PRI	TURBINE END SEAL: LEAKAGE KG/SEC SEC	TURBINE END SEAL: LEAKAGE KG/SEC TOTAL
1	1	2.5	3351.04	294.3	1,654,741.7	34,473.786	3,447.3786	.0480	.0385	.0866	68,947.572	77,566.019	.0548	.0190	.0739
	2	2.5			3,199,167.3	103,421.358	3,447.3786	.0589	.0403	.0857	172,368.93	263,724.463	.0943	.0181	.1124
	3	2.5			6,687,914.5	224,079.609	3,447.3786	.1043	.0430	.1474	275,790.288	156,777.665	.1428	.0190	.1619
2	4	2.5			6,618,966.9	430,922.325	10,342.1358	.0970	.0412	.1383	275,790.288	405,056.986	.1306	.0167	.1474
	5	2.5			10,135,293.1	396,448.539	17,236.8930	.1555	.0185	.1741	499,869.897	723,949.506	.2140	.0090	.2231
	6	1.75			13,444,776.5	586,054.362	730,844.2632	.2168	.0117	.2286	741,186.399	999,739.794	.2948	.0167	.3116
3	7	2.5			13,651,619.3	706,712.613	89,631.8436	.2431	.0290	.2721	741,186,399	999,739,794	.3048	.0195	.3243
	8				17,236,893.0	888,739.794	55,158.0576	.3238	.0458	.3696	982,502.901	1,336,203.950	.3941	.0244	.4186
	9				20,684,271.6	1,378,951.44	99,973.9794	.4318	.0657	.4975	1,292,766.975	1,663,704.912	.4799	.0385	.5184
4	10				18,271,106.6	1,809,873.765	106,868.7366	.3996	.0585	.4581	1,137,634.938	1,508,572.875	.4472	.0358	.4830
	11				20,856,640.5	2,120,137.839	168,921.5514	.4699	.0771	.5470	1,396,188.335	1,827,110.658	.5279	.0435	.5715
	12				22,063,223.0	2,240,796.09	189,605.8230	.4984	.0802	.5787	1,499,609.691	974,229.192	.5579	.0512	.6091
5	13			488.7	3,619,747.5	137,895.144	5,171.0679	.0548	.0385	.0934	17,236.893	172,368.930	.5220	.0172	.0857
	14			528.7	6,894,757.2	557,580.576	3,447.3786	.1333	.0358	.1691	60,329.1255	560,199.023	.1415	.0261	.1696
	15			499.8	10,514,504.7	853,226.204	49,986.9897	.1964	.0367	.2331	112,039.8045	853,226.204	.2041	.0426	.2467
	16			423.7	14,478,990.1	965,266.008	22,407.9609	.2485	.0381	.2866	155,132.037	1,042,832.027	.2499	.0412	.2912
6	17			413.2*	17,753,999.0	1,206,582.51	41,368.5432	.2884	.0371	.3256	224,079.609	1,267,256.373	.3102	.0480	.3583
	18			391.5*	21,890,854.1	1,456,862.196	36,197.4753	.3619	.0367	.3987	366,464.1514	1,594,757.340	.3760	.0585	.4345
	19			384.3*	24,131,650 2	1,551,320.37	25,866.3395	.3837	.0367	.4204	361,974.753	1,620,267.942	.4018	.0585	.4603
	20			379.3*	26,027,708.4	1,654,741.728	43,092.2325	.4227	.0376	.4603	310,264.074	1,378,951.440	.3492	.1211	.4703
7	21			459.8	25,510,601.6	1,844,347.551	101,697.6687	.4463	.0530	.4994	293,027.181	1,861,584.444	.4327	.0689	.5016
	22			526.5	25,510,601.6	2,171,848.518	241,316.502	.4817	.0857	.5674	379,211.646	2,223,559.197	.4826	.1038	.5864
	23			505.4	25,510,601.6	2,102,900.946	234,421.7448	.4694	.0825	.5520	387,830.0925	2,137,374.732	.4771	.1011	.5783
	24			497.0	24,993,494.9	2,085,664.053	227,526.9876	.4980	.0834	.5815	405,411.7234	2,258,032.983	.4975	.1052	.6028
	25			527.6	25,165,863.8	2,292,506.769	287,856.1131	.5116	.1011	.6128	422,303.8785	2,482,112.592	.5361	.1242	.6604
	26			499.8	25,165,863.8	2,171,848.518	224,079.609	.4857	.0834	.5692	439,885.509	2,413,165.02	.5261	.1197	.6459
	27			477.6	25,682,970.6	2,309,743.662	248,211.2592	.5379	.0889	.6268	1,827,110.658	2,551,060.164	.5538	.1315	.6853
	28			510.9	25,165,865.8	2,482,112.592	310,264.074	.5493	.1043	.6536	2,240,796.09	2,792,376.666	.5828	.1229	.7057
	29			519.3	25,165,865.8	2,516,586.378	329,569.3942	.5574	.1106	.6681	2,068,427.16	2,809,613.559	.5982	.1215	.7198
8	30			395.4	23,959,281.3	801,860.2624	120,658.251	.2408	.0439	.2848	888,044.727	1,103,161.152	.2775	.0907	.3683
	31			373.2	24,648,757.0	1,706,452.407	17,236.893	.4785	.0385	.5170	1,603,031.049	1,637,504.835	.4055	.2136	.6191
	32			372.0	24,304,019.1	1,706,452.407	10,342.1358	.4771	.0381	.5152	1,999,479.588	2,102,900.946	.5075	.1034	.6109
	33			402.6	23,786,912.3	1,827,110.658	86,184.465	.4839	.0539	.5379	2,085,664.053	2,258,032.983	.5184	.1179	.6363
	34			383.2	23,959,281.3	1,723,689.3	48,263.3004	.4785	.0444	.5229	1,982,242.695	2,189,085.411	.5130	.1079	.6209

*VALUES ARE LOWEST RECORDED. ACTUAL TEMPERATURE VARIANCE WAS FROM 491.5 TO 379.25

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP. K	INLET PR N/M^2	PUMP END SEAL PR DRAIN N/M^2	PUMP END SEAL SEC DRAIN N/M^2	PUMP END SEAL LEAKAGE KG/SEC PRI	PUMP END SEAL LEAKAGE KG/SEC SEC	PUMP END SEAL LEAKAGE KG/SEC TOTAL	TURBINE END SEAL PRI DRAIN N/M^2	TURBINE END SEAL SEC DRAIN N/M^2	TURBINE END SEAL LEAKAGE KG/SEC PRI	TURBINE END SEAL LEAKAGE KG/SEC SEC	TURBINE END SEAL LEAKAGE KG/SEC TOTAL
8 (CONT.)	35	2.5	3351.04	391.5	23,786,912.3	1,740,926.193	51,710.679	.4771	.0476	.5248	2,033,953.374	2,223,559,197	.5075	.1065	.6141
	36			360.9	23,786,912.3	1,723,689.3	51,368.5432	.4540	.0394	.4935	1,482,372.798	1,534,083.477	.3914	.2100	.6014
	37			374.8	23,959,281.3	1,792,636.872	55,158.0576	.4785	.0439	.5225	1,999,479.588	2,102,900.946	.5084	.1147	.6232
	38			373.2	24,131,650.2	1,809,873.765	41,368.5432	.4785	.0439	.5225	1,999,479.588	2,120,137.839	.5093	.1147	.6241
	39			372.0	23,786,912.3	1,758,165.086	41,368.5432	.4622	.0421	.5043	1,965,005.802	2,033,953,374	.5252	.1111	.6363
	40			388.7	23,786,912.3	1,878,821.337	72,394.9506	.4826	.0480	.5307	2,051,190.267	2,154,611.625	.5184	.1233	.6418
	41			388.7	23,614,543.4	1,878,821.337	55,158.0576	.4889	.0467	.5356	2,033,953.374	2,137,374.732	.5121	.1202	.6323
	42			387.0	23,442,174.5	1,861,584.444	51,710.679	.4835	.0467	.5302	2,016,716.481	2,137,374.732	.5003	.1179	.6182
	43			377.6	23,786,912.3	1,878,821.337	34,473.786	.4898	.0435	.5334	2,033,953.374	2,137,374.732	.5066	.1188	.6255
	44			385.9	23,614,543.4	1,878,821.337	51,710.679	.4889	.0498	.5388	2,016,716.481	2,154,611.625	.5057	.1206	.6264
	45			378.7	23,786,912.3	1,844,347.551	41,368.5432	.4880	.0458	.5338	1,999,479.588	2,120,137.839	.5048	.1161	.6209
	46			375.9	23,614,543.4	1,827,110.658	68,947.572	.4880	.0462	.5343	1,965,005.802	2,171,848.518	.5057	.1161	.6218
	47			399.8	23,614,543.4	1,896,058.23	96,526.6008	.4767	.0539	.5307	1,585,794.156	1,758,163.086	.3978	.1206	.5184
	48			376.2	1,499,609.7	1,758,163.086	44,815.922	.4785	.0435	.5220	1,930,532.016	2,154,611.625	.4962	.1115	.6078
	49			380.4	1,551,320.4	1,740,926.193	48,263.300	.4672	.0453	.5125	1,896,058.230	2,120,137.839	.4853	.1111	.5964
	50			372.0	1,447,899.0	1,861,584.444	51,710.680	.4848	.0435	.5284	[illegible],016,716.481	2,240,796.090	.5166	.1156	.6232
	51			385.9	1,620,267.9	1,809,873.765	51,710.680	.4907	.0471	.5379	[illegible],965,005.802	2,189,085.411	.4944	.1133	.6078
	52			405.4	1,861,584.4	1,999,479.588	103,421.358	.4844	.0576	.5420	[illegible],568,557.263	1,723.689.300	.4005	.2326	.6332
	53			392.6	1,703,005,0	1,878,821.337	75,842.330	.4867	.0517	.5384	1,947,768.909	1,447,899.012	.5030	.1229	.6259
	54			375.9	1,496,162.3	1,809,873.765	51,710.680	.4839	.0444	.5284	1,913,295.123	2,085,664.053	.5007	.1188	.6196
	55			406.5	1,875,374.0	2,051,190.267	110,316.115	.5347	.0625	.5973	2,120,137.839	2,344,217.448	.5443	.1342	.6785
	56			383.2	1,858,794.2	1,896,058.230	62,052,815	.5057	.0503	.5561	1,999,479.585	2,171,848.518	.5220	.1215	.6436
	57			375.9	1,496,162.3	1,827,110.658	55,158.058	.4980	.0503	.5483	1,930,532.016	2,137,374.732	.5084	.1188	.6273
	58			416.5	1,999,479.6	1,896,058.230	93,079.222	.7584	.0566	.8151	1,982,242.695	2,137,374.732	.4939	.1211	.6150
	59			398.2	1,771,952.6	1,896,058.230	62,052.815	.7207	.0526	.7733	1,982,242.695	2,154,611.625	.5057	.1161	.6218
	60			385.9	1,620,268.0	1,827,110.658	44,815.922	.6803	.0494	.7298	1,913,295.123	2,068,427.160	.4953	.1111	.6064
	61			375.9	1,496,162.3	1,827,110.658	62,052.815	.4889	.0462	.5352	1,930,532.016	2,102,900.946	.4989	.1188	.6177
	62			374.8	1,482,372.8	1,740,926.193	51,710.680	.4644	.0408	.5053	1,827,110.658	1,999,479.588	.4812	.1170	.5982
	63			383.2	1,585,794.2	1,827,110.658	65,500.193	.4785	.0480	.526[illegible]	1,896,058.230	2,085,664.053	.4880	.1233	.6114
	64			380.4	1,441,320.4	1,827,1[illegible]58	68,947.572	.4794	.0444	.5238	1,930,532.016	2,102,900.946	.4953	.1183	.6137
	65			403.7	1,840,900.2	1,930,53[illegible]6	103,421.358	.4867	.0557	.542[illegible]	1,947,768.909	2,171,848.518	.4975	.1283	.6259
	66			387.0	1,634,057.5	1,792,636.872	58,605.440	.4853	.0471	.532[illegible]	1,878,821.337	2,102,900.946	.4953	.1197	.6150
	67			377.6	1,516,846.6	1,775,399.979	51,710.680	.4848	.0435	.5284	1,878,821.337	2,102,900.946	.5007	.1165	.6173
	68			377.6	1,516,846.6	1,792,636.872	51,710.680	.4740	.0449	.5189	1,878,821.337	2,102,900.946	.5007	.1161	.6168

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M^2	PUMP END SEAL PR DRAIN N/M^2	PUMP END SEAL SEC DRAIN N/M^2	PUMP END SEAL LEAKAGE KG/SEC PRI	PUMP END SEAL LEAKAGE KG/SEC SEC	PUMP END SEAL LEAKAGE KG/SEC TOTAL	TURBINE END SEAL PRI DRAIN N/M^2	TURBINE END SEAL SEC DRAIN N/M^2	TURBINE END SEAL LEAKAGE KG/SEC PRI	TURBINE END SEAL LEAKAGE KG/SEC SEC	TURBINE END SEAL LEAKAGE KG/SEC TOTAL
8 (CONT.)	69	2.5	3351.04	399.8	1,792,637.0	1,861,584.444	89,631.844	.4894	.0503	.5397	1,965,005.802	2,171,848.518	.5057	.1238	.6295
	70			373.2	1,461,688.5	1,723,689.3	41,368,543	.4690	.0435	.5125	1,827,110.658	2,016,716.481	.4848	.1237	.6146
	71			372.0	1,447,899.0	1,723,689.3	48,263.300	.4735	.0439	.5175	1,827,100.658	2,033,953.374	.4903	.1143	.6137
	72			378.7	1,530,636.1	1,775,399.979	62,052.[illegible]	.4821	.0462	.5284	1,878,821.337	2,102,900.946	.5048	.1161	.6209
	73			374.81	1,482,372.8	1,706,452.407	48,263.[illegible]	.4644	.0435	.5080	1,792,636.872	1,999,479.588	.4812	.1106	.5919
	74			381.48	1,565,109.9	1,740,926.193	55,158.058	.4672	.0471	.5143	1,844,347.551	2,033,953.374	.4844	.1156	.6001
	75			377.6	23,097,436.6	1,775,399.980	58,605.4362	.4812	.0498	.5311	1,861,584.444	2,085,664.053	.4980	.1211	.6191
	76			383.2	22,580,329.8	1,740,326.193	62,052.8148	.0544	.0485	.5134	1,827,110.658	2,033,953.374	.4889	.1192	.6082
	77			397.0	23,097,436.6	1,913,295.123	113,763.4938	.0535	.0553	.5556	[illegible],551,320.37	1,740,926.193	.4173	.2381	.6554
	78			384.3	23,269,805.6	1,827,110.660	75,842.3292	.0576	.0485	.5515	1,896,058.23	2,187,374.732	.5102	.1292	.6395
	79			383.2	22,752,698.8	1,758,163.090	62,052.8148	.0557	.0462	.5170	1,844,347.551	2,051,109.267	.4980	.1233	.6214
	80			394.3	22,580,329.8	1,758,163.090	68,947.572	.0562	.0480	.5434	1,827,110.658	2,033,953.374	.4916	.1224	.6141
9	81			394.3	22,925,067.7	1,913,295.123	99,973.9794	.1229	.0544	.5379	1,878,821.337	2,102,900.946	.4889	.1338	.6227
	82			388.7	23,097,436.6	1,930,532.016	72,394.9506	.4689	.0485	.5075	1,913,295.123	2,137,374.732	.4989	.1283	.6273
	83			384.3	23,269,805.6	1,878,821.340	75,842.3292	.4907	.0539	.5447	1,896,058.23	2,120,137.839	.5016	.1301	.6318
	84			419.3	22,407,960.9	2,016,716.481	120,658.251	.5007	.0580	.5588	1,982,242.695	2,223,559.197	.4989	.1338	.6327
	85			389.8	22,752,698.8	1,878,821.340	62,052.8148	.4898	.0485	.5384	1,878,821.337	2,102,900.946	.4944	.1283	.6001
	86			389.8	22,925,067.7	1,896,056.23	79,289.7078	.4880	.0503	.5384	1,930,532.016	2,120,137.839	.4926	.1265	.6191
	87			392.6	22,752,690.8	1,896,058.23	79,289.7078	.4803	.0508	.5311	1,913,295.123	2,102,900.946	.4907	.1247	.6155
	88			381.5	22,580,[illegible]	1,844,347.551	65,500.1934	.4681	.0489	.5170	1,844,347.551	2,085,664.053	.4812	.1224	.6037
	89			398.2	22,580,32[illegible]	1,930,532.016	86,184.465	.4762	.0539	.5332	1,965,005.802	2,137,374.732	.4862	.1270	.6132
	90			381.5	22,5[illegible],329.8	1,792,636.872	65,500.1934	.4603	.0471	.5075	1,809,873.765	2,016,716.481	.4848	.1279	.6128
	91			384.3	22,752,698.8	1,947,768.909	82,737.0864	.4785	.0521	.5307	1,982,242.695	2,154,611.625	.5016	.1338	.6354
	92			384.3	22,307,960.8	1,913,295.123	93,079.2222	.4862	.0553	.54[illegible]5	1,965,005.802	2,102,900.946	.5039	.1374	.6413
	93			405.4	22,580,329.8	2,016,716.481	113,763.4938	.5093	.0589	.5683	2,016,716.481	2,223,559.197	.5193	.1383	.6577
	94			384.3	22,925,067.7	1,982,242.695	79,289.7078	.5166	0535	.57[illegible]1	1,965,005.802	2,1[illegible],085.411	.5279	.1356	.6636
	95			375.9	22,580,329.8	1,947,768.909	72,394.9506	.5075	.0553	.56[illegible]9	1,982,242.695	2,154,611.625	.5175	.1324	.6499
	96			374.8	22,580,329.8	1,947,768.909	68,947.572	.5007	.0553	.5561	1,913,295.123	2,137,374.732	.5111	.1306	.6418
	97			374.8	22,407,960.9	1,947,768.909	65,500.1934	.4935	.0539	.5747	1,982,242.695	2,120,137.839	.5111	.1297	.6409
	98			377.6	22,063,223.0	1,947,768.909	68,947.572	.4916	.0562	.5479	1,896,058.23	2,120,137.839	.4962	.1297	.6259
	99			378.7	22,063,223.0	1,965,005.802	68,947.572	.4916	.0535	.545[illegible]	1,982,242.695	2,120,137.839	.5007	.1279	.6286
	100			381.5	22,235,592.0	2,016,716.481	75,842,3292	.5025	.0498	.5521	2,033,953.374	2,171,848.518	.5066	.1329	.6395
	101			380.4	22,235,592.0	1,982,242.695	110,316.1152	.5057	.0616	.5671	1,947,768.909	2,154,611.625	.5030	.1428	.6459
	102			366.5	22,407,960.9	1,947,768.909	75,842.3292	.5180	.0544	.5721	1,930,532.016	2,120,137.839	.5148	.1369	.6518

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M^2	PUMP END SEAL PR DRAIN N/M^2	PUMP END SEAL SEC DRAIN N/M^2	PUMP END SEAL LEAKAGE KG/SEC PRI	PUMP END SEAL LEAKAGE KG/SEC SEC	PUMP END SEAL LEAKAGE KG/SEC TOTAL	TURBINE END SEAL PRI DRAIN N/M^2	TURBINE END SEAL SEC DRAIN N/M^2	TURBINE END SEAL LEAKAGE KG/SEC PRI	TURBINE END SEAL LEAKAGE KG/SEC SEC	TURBINE END SEAL LEAKAGE KG/SEC TOTAL
9	103			363.7	22,407,960.9	1,965,005.802	72,394.9506	.5266	.0535	.5801	1,878,821.337	2,120,137.839	.5170	.1369	.3540
	104	2.5	3351.04	375.9	22,063,223.0	2,016,716.4[illegible]	86,184.465	.5225	.0576	.5801	1,930,532.016	2,137,374.732	.5130	.1365	.6495
	105			360.9	21,890,854.1	1,947,768.909	68,947.572	.5234	.0557	.5792	1,930,532.016	2,102,900.946	.5139	.1338	.6477
	106			364.8	21,546,116.3	1,947,768.909	75,842.3292	.5216	.0562	.5778	1,861,584.444	2,102,900.946	.5121	.1338	.6459
	107	1.92		519.3	18,788,213.4	2,102,900.946	241,316.502	.4894	.1229	.6123	3,137,114.526	3,585,273.744	.5116	.2912	1.075
10	PRE 108 STATIC LEAK		0	302.6	3,447,378.6	448,159.218	10,342.1358	.1211	.0185	.139	310,264.074	430,922.325	.1283	.1995	.1483
			0	297.0	6,894,757.2	948,029.115	113,763.4938	.2485	.0376	.2862	689,475.720	137,895.144	.2558	.0417	.2975
			0	290.4	10,342,135.8	1,447,899.012	230,974.3662	.3746	.0585	.4331	896,318.436	310,264.074	.3828	.0639	.4467
			0	290.4	13,789,514.4	1,809,873.8	179,263.6872	.4844	.0779	.5824	1,172,108.724	465,396.111	.5161	.0866	.6028
			0	293.1	16,547,417.2	1,965,005.802	337,843.1028	.5461	.1537	.6998	1,344,477.654	551,580.576	.6010	.1011	.7021
			0	297.6	19,994,795.8	2,706,192.201	286,132.4238	.6980	.1374	.8355	2,861,324.238	844,607.757	.6976	.1569	.8545
	108	2.5	3089.24	495.4	3,619,747.5	361,974.753	3,447,3786	.0861	.0403	.1265	396,448.539	17,236.893	.0997	.0172	.1170
	109		3089.24	533.2	6,722,388.2	758,423.292	3,447.3786	.1524	.0385	.1909	792,897.078	120,658.251	.1655	.0272	.1927
	110		3115.42	527.6	10,342,135.8	1,378,951.440	10,342.1358	.2662	.0381	.3043	1,344,477.654	344,737.860	.2753	.0598	.3352
	111		3089.24	516.5	13,444,776.5	1,737,478.814	62,052.8148	.3447	.0394	.3841	1,806.426.386	430,922.325	.3483	.0680	.4163
11	112	2.7	3036.88	480.4	17,064,524.1	1,965,005.802	279,237.6666	.4377	.0689	.5066	2,068,427.160	620,538.148	.4368	.0979	.5347
	113	2.9	3036.88	498.1	20,339,533.7	2,585,533.950	134,447.7654	.5434	.0399	.5833	2,654,481.522	586,054.362	.5365	.0911	.6277
	114	2.5	3036.88	459.3	22,407,960.9	2,792,376.666	206,842.7160	.6082	.1070	.7153	2,8[illegible]6,166.180	737,739.020	.6032	.1170	.7203
	115	3.0	3036.88	505.4	23,614,543.4	2,723,429.094	199,947,9588	.5629	.0952	.6581	2,826,850.452	806,686.592	.565	.1179	.6835
12	116	2.5	3089.24	529.8	23,442,174.4	2,557,954.921	246,142.8320	.5216	.1097	.6314	2,902,692.781	903,213.193	.566	.1247	.6917
	117		3010.70	513.7	22,132,170.61	2,592,428.707	148,237.2798	.5166	.0839	.6005	2,620,007.736	948,029.115	.5184	.1446	.6631
	118		2994.99	506.5	24,131,650.2	2,757,902.88	155,132.0370	.5583	.0938	.6522	2,782,034.530	1,075,582.123	.5524	.1610	.7135
	119		3052.58	521.5	25,510,601.6	2,850,982.102	172,368.9300	.5715	.0943	.6658	3,188,825.205	1,034,213.580	.5710	.1573	.7284
	120		2947.86	509.8	24,648,756.9	2,954,403.460	194,432.1530	.5851	.0943	.6794	3,230,193.748	1,006,634.551	.5991	.1555	.7547
	121		3047.35	530.9	24,131,650.2	2,930,271.810	179,263.6872	.5620	.0970	.6590	3,247,430.641	844,607.757	.6014	.1288	.7302
	122		3193.96	515.9	25,510,601.6	2,954,403.460	206,842.7160	.5892	.1052	.6944	3,154,351.419	1,103,161.152	.5724	.1651	.7375
	123		2984.52	524.8	25,855,339.5	2,792,376.666	193,053.2016	.5529	.1038	.6568	3,144,009.283	1,068,687.366	.5579	.1642	.7221
	124		2785.55	522.0	24,717,704.5	2,930,271.810	182,711.0658	.5860	.1056	.6917	3,171,588.312	972,160.765	.5465	.1510	.6976
	125		2947.86	533.2	24,717,704.5	2,826,850.452	217,184.8518	.5932	.1097	.7030	3,171,588.312	1,027,318.822	.5733	.1419	.7153
	126		2932.16	483.7	24,304,019.1	2,706,192.201	184,090.0172	.6137	.0966	.7103	3,068,166.954	1,068,687.366	.5892	.1605	.7457
	127		2932.16	533.2	24,648,756.9	2,954,403.460	206,842.7160	.5901	.0993	.6894	3,343,957.242	965,266.008	-	.1460	-
	128		3036.88	533.2	24,131,650.2	2,895,798.0	193,053.20	.5756	.0916	.6672	3,309,483.5	896,318.4	.6032	.1474	.7506
	129		3036.88	533.2	23,786,912.3	2,885,455.9	184,090.12	.5787	.0916	.6704	3,302,588.7	903,213.2	.5887	.1270	.7157
	130		3036.88	533.2	25,407,180.3	2,844,087.4	210,290.09	.5656	.0991	.6645	3,240,535.9	885,976.3	.5828	.1238	.7066

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M^2	PUMP END SEAL PR DRAIN N/M^2	PUMP END SEAL SEC DRAIN N/M^2	PUMP END SEAL LEAKAGE KG/SEC PRI	PUMP END SEAL LEAKAGE KG/SEC SEC	PUMP END SEAL LEAKAGE KG/SEC TOTAL	TURBINE END SEAL PRI DRAIN N/M^2	TURBINE END SEAL SEC DRAIN N/M^2	TURBINE END SEAL LEAKAGE KG/SEC PRI	TURBINE END SEAL LEAKAGE KG/SEC SEC	TURBINE END SEAL LEAKAGE KG/SEC TOTAL
12	131	2.5	2916.452	510.9	235,455.958.4	2,913,034.9	210,290.09	.5928	.0948	.6876	3,343,957.2	896,318.4	.5951	.1270	.7221
	132		3000.228	508.7	24,821.125.9	2,654,481.5	181,332.11	.5728	.0934	.6663	3,033,693.2	1,068,687.4	.5556	.1528	.7085
	133		3036.88	515.9	24,993,494.9	2,654,481.5	179,263.69	.5769	.0914	.6685	3,047,482.7	1,034,213.6	.5434	.1528	.8777
	134		3036.88	527.6	24,372,966.7	2,930,271.8	179,263.69	.5597	.0986	.6581	3,171,588.3	982,502.9	.5461	.1415	.6876
	135		3036.88	530.4	24,200,597.8	2,930,271.8	193,053.20	.5597	.1018	.6613	3,171,588.3	1,034,213.6	.5678	.1514	.7193
	136		3036.88	533.2	24,304,019.1	2,930,271.8	206,842.72	.5597	.0985	.6581	3,185,377.8	1,103,161.152	.5542	.1583	.7125
	137		3036.88	504.3	23,959,281.3	2,919,929.7	203,395.34	.570[illegible]	.0992	.6699	3,171,558.3	1,023,871.4	.5778	.1501	.7280
	138		3010.70	507.6	23,683,491.0	2,913,034.9	193,053.20	.5678	.0951	.6631	3,068,166.9	1,127,292.8	.5456	.1619	.7076
	139		2994.992	492.6	24,200,597.8	2,809,613.5	213,737.47	.5624	.1041	.6663	3,033,693.2	1,041,108.3	.5470	.1587	.7057
	140		3010.70	533.2	24,131,650.2	2,964,745.6	199,947.96	.5443	.1023	.6468	3,102,640.7	1,241,056.3	.5211	.1728	.6939
	141		3036.88	502.6	23,087,436.6	2,482,112.6	168,921.55	.5089	.1060	.6150	2,502,796.9	1,214,856.2	.4472	.1809	.6282
	142		3036.88	494.3	24,372,966.7	2,826,850.5	224,079.61	.5656	.1067	.6722	2,909,587.5	1,344,477.7	.5234	.2013	.7248
	143		2984.52	489.8	24,476,388.1	2,854,429.5	220,632.23	.5774	.1034	.6808	2,882,008.5	1,314,830.2	.5257	.1964	.7221
	144		3036.88	516.5	22,752,698.8	2,482,112.6	199,947.96	.4916	.1106	.6023	2,344,217.5	1,249,330.0	.4262	.1900	.6164
	145		3099.712	535.9	24,821,125.9	2,913,034.9	195,121.63	.5620	.1011	.6631	3,116,430.3	1,413,425.2	.5198	.1973	.7171
	146		3089.24	530.4	24,752,178.4	2,947,508.7	194,432.15	.5620	.1029	.6649	3,157,798.8	1,396,188.3	.5443	.1954	.7398
	147		3036.88	522.6	24,407,440.5	2,826,850.5	193,053.20	.5483	.0997	.5483	2,895,798.0	1,547,872.9	.4912	.2159	.7071
	148		3036.88	.531.5	24,717,704.6	2,878,561.1	194,432.15	.5706	.1029	.6735	2,999,219.4	1,559,594.1	.5084	.2168	.7252
	149		2869.328	523.7	24,407,440.5	2,895,798.0	193,053.20	.5760	.1056	.6817	3,323,272.9	1,141,082.3	.5778	.1646	.7425
	150		3036.88	533.2	24,752,178.4	2,819,955.7	193,053.20	.5706	.1029	.6735	2,895,798.0	1,482,372.8	,5143	.2054	.7198
	151		3036.88	516.5	24,476,388.1	2,826,850.5	191,674.25	.5574	.1016	.6590	3,240,535.9	1,103,161.52	.5633	.1682	.7316
	152		2932.16	525.4	24,821,125.9	2,888,903.3	220,632.23	.5756	.1056	.6892	3,033,693.2	1,559,594.0	.5111	.2236	.7348
	153		2974.048	504.8	24,821,125.9	2,826,850.5	272,342.91	.5860	.1052	.6912	2,909,587.5	1,551,320.4	.4482	.2277	.6758
	154		2958.34	529.8	24,890,073.5	2,823,403.1	265,448.15	576.5	.1052	.6817	2,861,324.2	1,585,794.2	.4371	.2286	.6658
	155		3026.408	523.7	25,441,654.1	2,902,692.8	262,000.77	.5742	.1038	.6781	2,792,376.6	1,478,925.4	.4558	.2136	.6695
	156		2932.16	489.8	24,476,388.1	2,888,903.3	268,895.5	.5887	.1070	.6958	2,930,271.8	1,568,557.3	.4912	.2290	.7203
	157		3036.88	527.0	24,476,388.1	2,826,850.5	241,316.5	.5728	.1002	.6731	2,895,798.0	1,387,225.1	.4681	.2258	.6939
	158		3036.88	560.4	24,648,756.9	2,937,166.6	224,079.6	.5796	.1030	.6826	3,068,166.9	1,275,530.0	.540[illegible]	.1879	.7284
13	PRE		-	299.8	24,752,178.3	413,685.4	13,789.5	.1283	.0439	.1723	248,211.3	68,947.6	.1315	.0308	.1623
	159		-	294.3	3,447,378.6	89,631.8	41,368.5	.2535	.0535	.3070	482,633.0	241,316.5	.2676	.0566	.3243
	STATIC LEAK		-	288.7	6,894,757.2	1,437,556.9	96,526.6	.4055	.0712	.4767	758,423.3	439,196.0	.4114	.0907	.5021
			-	289.3	10,342,135.8	1,861,584.4	155,132.0	.5329	.0938	.6268	979,055.5	611,564.9	.5347	.1242	.6590
			-	293.1	13,789,514.4	2,223,559.2	210,290.1	.5317	.1156	.8972	1,179,003.5	744,633.8	.7946	.1800	.9747
			-	299.8	16,547,417.28	2,557,954.9	248,211.3	.7252	.1283	.8536	1,378,951.4	896,318.4	.7447	.1691	.9139

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M^2	PUMP END SEAL PR DRAIN N/M^2	PUMP END SEAL SEC DRAIN N/M^2	PUMP END SEAL LEAKAGE KG/SEC PRI	PUMP END SEAL LEAKAGE KG/SEC SEC	PUMP END SEAL LEAKAGE KG/SEC TOTAL	TURBINE END SEAL PRI DRAIN N/M^2	TURBINE END SEAL SEC DRAIN N/M^2	TURBINE END SEAL LEAKAGE KG/SEC PRI	TURBINE END SEAL LEAKAGE KG/SEC SEC	TURBINE END SEAL LEAKAGE KG/SEC TOTAL
13	159	2.5	3036.88	463.7	19,305,320.2	2,688,955.3	193,053.2	.5756	.0957	.6713	2,895,798.0	751,528.5	.6078	.1183	.7262
(CONT.)	160	1.3	3036.88	533.2	22,683,751.1	2,661,376.3	179,263.7	.5252	.0920	.6173	2,895,798.0	758,423.3	.5892	.1147	.7039
	161	2.5	3036.88	533.2	23,959,281.3	2,557.954.9	165,474.2	.5275	.0884	.6159	2,826,850.5	723,949.5	.5728	.1111	.6840
	162		3026.408	516.5	22,752,698.8	2,633,797.3	193,053.2	.5615	.0979	.6595	2,792,376.7	820,476.1	.5860	.1310	.7171
	163		3036.88	533.2	24,821,125.9	2,888,903.3	193,053.2	.5765	.1061	.6826	3,136,114.5	889,423.7	.6291	.1360	.7652
	164		3036.88	533.2	25,510,601.6	2,757,902.8	193,053.2	.5443	.0988	.6431	3,019,903.7	875,634.2	.5910	.1274	.7184
	165		3036.88	533.2	24,752,178.3	2,723,429.1	191,674.3	.5642	.0984	.6626	2,964,745.6	848,055.1	.5969	.1270	.7239
	166		3036.88	490.9	24,304,019.1	2,730,323.9	206,842.7	.5937	.1038	.6976	2,916,482.3	772,212,8	.6245	.1224	.7470
	167		3036.88	533.2	24,821,125.9	2,861,324.2	184,779.5	.5819	.0970	.6790	3,157,798.8	772,212.8	.6191	.1124	.7316
	168		2974.048	517.0	24,821,125.9	2,792,376.7	205,463.8	.5805	.1038	.6844	2,930,271.8	868,739.4	.6114	.1319	.7434
	169		3036.88	520.4	25,269,285.1	2,826,850.5	198,569.0	.5805	.1034	.6840	3,033,693.2	868,739.4	.6268	.1319	.7588
	170		2827.44	533.2	25,165,863.8	2,757,902.8	212,358.5	.5756	.1038	.6794	2,978,535.1	875,634.2	.6050	.1356	.7404
	171		3036.88	533.2	24,993,494.9	2,702,744.8	206,842.7	.5756	.1011	.6767	2,888,903.3	854,949.9	.5919	.1329	.7248
	172		2984.52	527.5	24,648,756.9	2,688,955.3	193,053.3	.5715	.0984	.6699	2,964,745.6	848,055.1	.5937	.1319	.7257
	173		2927.44	533.2	24,131,650.2	2,702,744.8	186,158.4	.5810	.0979	.6790	3,019,903.7	841,160.4	.5996	.1301	.7298
	174		3010.70	527.6	24,821,125.9	2,702,744.8	182,711.1	.5783	.0988	.6772	2,964,745.6	827,370.9	.5932	.1260	.7193
	175		2984.52	530.4	25,165,863.8	2,757,902.9	193,053.2	.5869	.1029	.6899	3,063,166.9	896,317.4	.6128	.1401	.7529
	176		2879.80	510.9	24,752,178.3	2,757,902.9	205,463.8	.5996	.1011	.7008	3,095,745.9	923,897.5	.6132	.1433	.7565
	177		2958.34	528.2	25,165,863.8	2,757,902.9	206,153.2	.5942	.1002	.6944	3,157,798.8	965,266.0	.6087	.1465	.7552
	178		2974.048	508.1	25,234,811.4	2,751,008.1	199,948.0	.6059	.1016	.7076	3,102,640.7	985,950.3	.6250	.1524	.7774
	179		3036.88	533.2	24,821,125.9	2,957,850.8	179,263.7	.6046	.0993	.6903	3,240,535.9	882,528.9	.6318	.1297	.7615
	180		2984.52	522.0	24,476,388.1	2,792,376.7	203,395.3	.5964	.1038	.7003	3,047,482.7	999,739.8	.6273	.1528	.7801
	181		3036.88	525.9	24,821,125.9	2,826,850.5	193,053.2	.6005	.1025	.7030	3,171,588.3	999,739.3	.6441	.1510	.7951
	182		2958.34	519.3	24,304,019.1	2,757,902.9	193,053.2	.6019	.1002	.7021	3,171,588.3	1,013,529.3	.6001	.587	.7588
	183		3036.88	533.2	23,442,174.5	2,819,955.7	179,263.7	.5955	.0961	.6917	3,206,062.1	951,476.5	.6073	.1392	.7466
	184		3010.70	533.2	25,165,963.8	2,654,481.5	194,432.2	.5860	.0988	.6849	3,171,588.3	1,137,634.9	.6177	.1818	.7996
	185		3036.88	527.6	24,304,019.1	2,757,902.9	179,263.7	.5923	.0984	.6908	3,171,588.3	1,323,793.4	.6245	.1732	.7978
	186		2942.632	512.0	23,442,174.5	2,661,376.3	191,674.3	.6137	.1002	.7139	2,022,693.2	1,137,634.9	.6059	.1796	.7856
	187		3036.88	507.0	22,580,329.8	2,551,060.2	187,537.4	.5669	.1020	.6690	2,826,850.5	1,103,161.2	.5774	.1682	.7457
	188		3036.88	530.4	23,442,174.5	2,833,745.2	193,053.2	.5801	.0970	.6772	3,157,798.8	1,116,950.7	.6159	.1632	.7792
	189		2816.968	533.2	24,131,650.2	2,620,007.7	193,053.2	.5483	.1002	.6853	2,840,640.0	1,206,582.5	.5869	.1773	.7643
	190		3036.88	533.2	24,131,650.2	2,868,219.0	179,263.7	.5996	.0961	.6958	3,144,009.3	1,172,108.7	.6209	.1619	.7829
	191		3036.88	533.2	23,442,174.5	2,840,640.0	189,605.8	.5964	.0979	.6944	3,171,588.3	1,206,582.5	.6096	.1759	.7856
	192		3036.88	533.2	23,442,174.5	2,826,850.5	193,053.2	.6011	.1006	.7021	3,137,114.5	1,227,266.8	.6332	.1787	.8119

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PP N/M^2	PUMP END SEAL PR DRAIN N/M^2	SEC DRAIN N/M^2	LEAKAGE KG/SEC PPI	SEC	TOTAL	TURBINE END SEAL PRI DRAIN N/M^2	SEC DRAIN N/M^2	LEAKAGE KG/SEC PRI	SEC	TOTAL
13 (CONT.)	193	2.5	3036.88	533.2	22,752,698.8	2,806,166.2	189,166.2	.5892	.0975	.6867	3,137,114.5	1,137,634.9	.6164	.1642	.7806
	194		3036.88	533.2	23,786,912.3	2,826,850.5	193,053.2	.6059	.1006	.7066	3,185,377.8	1,275,530.1	-	.1855	-
	195		3036.88	533.2	22,063,223.0	2,771,692.4	182,711.1	.5774	.0957	.6731	3,019,903.7	1,130,740.2	.6023	.1614	.7638
	196		3015.936	533.2	22,683.751.2	2,757,902.9	179,263.7	.5824	.0966	.6790	3,033,693.2	1,206,582.5	.5919	.1737	.7656
	197		2984.52	530.4	23,442,174.5	2,792,376.7	213,737.5	.6037	.1025	.7062	3,171,588.3	1,310,003.9	.6277	.1932	.8210
	198		3036.88	533.2	24,062,702.6	2,833,745.2	203,395.3	.5801	.1002	.6985	3,150,904.0	1,310,003.9	.6209	.1873	.8083
	199		3141.60	533.2	23,924,807.5	2,840,640.0	206,153.2	.6028	.0993	.7021	3,157,798.8	1,303,109.1	.6191	.1859	.8051
	200		3036.88	533.2	24,131,650.2	2,888,903.3	215,116.4	.5987	.1025	.7012	3,150,904.0	1,351,372.4	.6196	.1982	.8178
	201		3036.88	533.2	24,131,650.2	2,826,850.5	189,695.8	.5923	.0997	.6921	3,102,740.7	1,275,530.1	.6114	.1832	.7946
	202		3036.88	502.6	22,925,067.7	2,751,008.1	193,053.2	.5991	.0984	.6976	3,026,798.4	1,316,898.6	.6186	.1959	.8146
	203		3120.666	532.6	23,442,174.5	2,854,429.5	193,053.2	.6001	.1006	.7008	3,144,009.3	1,344,477.7	.6141	.1918	.8060
	204		2932.16	527.6	22,925,067.7	2,599,323.5	191,674.3	.5570	.0997	.6568	3,013,008.9	1,344,477.7	.6005	.1936	.7942
	205		3036.88	533.2	23,786,912.3	2,895,798.0	195,121.6	.5982	.1025	.6917	3,171,588.3	1,344,477.7	.6332	.2018	.8350
	206		3036.88	533.2	23,097,436.6	2,826,859.5	191,674.3	.5837	.0988	.7008	3,137,114.5	1,310,003.9	.6295	.1791	.8087
	207		3036.88	516.5	24,304,019.1	2,806,166.2	206,842.7	.6082	.1034	.7116	3,137,114.5	1,468,583.3	.6395	.2118	.8513
	208		3036.88	533.2	23,442,174.5	2,819,955.7	193,053.2	.5951	.1025	.6976	3,102,640.7	1,441,004.3	.6105	.2004	.8110
	209		3089.24	533.2	23,614,543.4	2,833.745.2	196,500.6	.5942	.0984	.6926	3,136,114.5	1,447,899.0	.6105	.2036	.8141
	210		3036.88	533.2	23,614,543.4	2,819,955.7	193,053.2	.4887	.0975	.6862	3,088,851.2	1,426,214.0	.6104	.2000	.8105
	211		3089.24	533.2	23,786,912.3	2,833,745.2	193,053.2	.5932	.0997	.6930	3,171,588.3	1,441,004.3	.6105	.2023	.8128
	212		3036.88	532.0	23,097,436.6	2,757,902.9	180,642.6	.5837	.0966	.6803	3,033,693.2	1,365,161.9	.5919	.1973	.7892
	213		3036.88	533.2	23,442,174.5	2,861,324.2	195,121.6	.6137	.1043	.7180	3,171,588.3	1,509,951.8	.6118	.2122	.8241
	214		3036.88	533.2	22,407,950.9	2,702,744.8	196,500.6	.5951	.1047	.6998	2,964,745.6	1,413,425.2	.5928	.2181	.8110
	215		3036.88	533.2	23,442,174.5	2,854,429.5	199,948.0	.6023	.1034	.7057	3,109,535.5	1,482,372.8	.6118	.2050	.8169
	216		3089.24	533.2	23,614,543.4	2,861,324.2	206,842.7	.6037	.1047	.7085	3,102,640.7	1,475,478.0	.6141	.2091	.8232
	217		3089.24	533.2	23,097,436.6	2,861,324.2	205,463.8	.6046	.1025	.7071	3,116,430.3	1,413,425.2	.6109	.2086	.8196
	218		3089.24	533.2	23,269.805.6	2,826,859.5	193,053.2	.6991	.1025	.7026	3,068,167.0	1,482,372.8	.6105	.2195	.8300
14	PRE 219 STATIC LEAK	-	0	367.0	3,447,378.6	413,685.4	27,579.0	.1197	.1471	.1669	496,422.5	55,158.1	.1229	.1265	.2494
		-	0	365.4	6,894,757.2	1,016,976.7	72,395.0	.2517	.0612	.3129	1,103,161.2	172,368.9	.2685	.2739	.5424
		-	0	344.3	10,342,135.8	1,551,320.4	137,895.1	.3696	.0843	.4540	1,654,741.7	310,264.1	.3950	.3955	.7906
		-	0	316.5	13,789,514.4	2,009,821.7	208,221.7	.5320	.1084	.6404	2,220,111.8	465,396.1	.5620	.5520	1.1140
		-	0	294.5	15,237,413.4	2,240,796.1	235,800.7	.6273	.1143	.7416	2,468,323.1	551,580.6	.6513	.6377	1.2891
	219	2.5	2827.44	533.2	22,752,698.8	2,861,324.2	193,053.2	.5626	.1025	.6651	3,054,377.4	672.238.8	.4716	.2058	.7774
	220		2722.72	499.3	23,442,174.5	2,971,640.4	234,421.7	.6149	.1128	.7277	3,102,640.7	723,949.5	.6385	.2278	.8664
	221		2827.44	526.8	23,442,174.5	2,964,745.6	206,842.7	.6131	.1168	.7300	3,171,588.3	723,949.5	.6210	.2317	.8535

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M^2	PUMP END SEAL					TURBINE END SEAL				
						PR DRAIN N/M^2	SEC DRAIN N/M^2	LEAKAGE KG/SEC			PRI DRAIN N/M^2	SEC DRAIN N/M^2	LEAKAGE KG/SEC		
								PRI	SEC	TOTAL			PRI	SEC	TOTAL
14 (CONT.)	222	2.5	2932.16	525.4	24,131,650.2	293,027.2	210,290.1	.5990	.1123	.7113	3,088,851.2	775,660.2	.5974	.2386	.8361
	223			533.2	23,442,174.5	2,861,324.2	206,842.7	.5947	.1100	.7048	3,019,903.7	727,397.0	.5708	.2322	.80[illegible]0
	224			505.4	23,786,912.3	2,895,798.0	186,158.4	.6133	.1139	.7273	3,068,167.0	772,212.8	.6270	.2452	.8723
	225			533.2	23,614,543.4	2,861,324.2	182,711.1	.5877	.1042	.6920	3,026,798.4	827,370.8	.6949	.2421	.8105
	226			529.3	24,304,019.1	2,868,219.0	206,842.7	.6075	.1049	.7125	2,971,640.4	1,065,240.0	.5327	.3148	.8476
	227			533.2	23,545,595.8	2,957,850.8	208,221.7	.5970	.1041	.7012	2,826,850.5	970,437.1	.5402	.2789	.8191
	228			499.8	23,442,174.5	2,775,139.8	206,842.7	.6072	.1075	.7148	2,364,901.7	1,025,595.1	.5230	.3195	.8425
	229			496.5	23,614,543.4	2,819,955.7	219,253.3	.6105	.1091	.7197	2,220,111.8	1,310,003.9	.4398	.3989	.8388
	230			532.6	24,062,702.6	2,826,850.5	241,316.5	.5924	.1101	.7025	2,413,165.0	1,237,608.9	.4685	.3623	.8308
	231			533.2	22,063,223.0	2,740,666.0	203,395.3	.5566	.1028	.6595	1,944,321.5	1,272,082.7	.4014	.3596	.7611
	232			524.8	23,649,017.2	2,837,192.6	208,911.1	.5921	.1104	.7026	2,206,322.3	1,275,530.1	.4024	.3833	.7858
	233			520.7	24,131,650.2	3,033,693.2	262,000.8	.6154	.1169	.7324	1,813,321.1	1,551,320.4	.3787	.4603	.8339
	234			527.6	24,338,492.9	2,964,745.6	234,421.7	.6183	.1141	.7325	1,999,479.6	1,530,636.1	.3641	.4448	.8389
	235			533.2	24,131,650.2	2,923,377.1	234,421.7	.6006	.1109	.7116	2,413,165.0	1,361,714.5	.4226	.3910	.8136
	236			533.2	23,580,069.6	2,888,903.3	217,184.9	.5930	.1063	.6994	2,206,322.3	1,396,188.3	.4002	.3945	.7948
	237			520.7	24,131,650.2	2,878,561.1	213,737.5	.5974	.1040	.7014	2,206,322.3	1,430,662.1	.3791	.4217	.8009
	238			527.6	24,131,650.2	2,999,219.4	248,211.3	.6071	.1153	.7225	2,199,427.5	1,444,451.6	.4026	.4227	.8254
	239			533.2	23,614,543.4	2,854,429.5	217,874.3	.5834	.1044	.6878	2,378,691.2	1,310,003.9	.4262	.3945	.8207
	240			521.5	23,786,912.3	2,895,798.0	224,079.6	.5974	.1085	.7060	2,482,112.6	1,306,556.5	.4488	.3850	.8339
	241			510.9	24,131,650.2	2,913,034.9	234,421.7	.6029	.1099	.7128	2,206,322.3	1,447,899.0	.3933	.4199	.8132
	242			522.6	24,131,650.2	2,861,324.2	234.421.7	.6087	.1119	.7206	2,213,217.1	1,280,701.2	.4287	.3827	.8114
	243			533.2	23,442,174.5	2,826,850.4	213,737.5	.5848	.1036	.6884	2,358,007.0	1,272,082.7	.4198	.3661	.7859
	244			533.2	23,959,281.3	2,930,271.8	213,737.5	.5955	.1026	.6981	1,930,532.0	1,654,741.7	.3437	.4745	.8182
	245			533.2	23,442,174.5	2,757,902.9	206,842.7	.5804	.1989	.6793	2,240,796.1	1,387,569.9	.3921	.3982	.7919
	246			533.2	23,373,226.9	2,826,850.5	205,463.8	.5796	.1018	.6815	1,930,532.0	1,516,846.6	.3558	.4309	.7867
	247			533.2	23,786,912.3	2,861,324.2	220,632.2	.5941	.1031	.6972	1,758,163.1	1,585,794.2	.3491	.4569	.8061
	248			527.0	23,442,174.5	2,826,850.5	213,737.5	.5987	.1006	.6994	2,378,691.2	1,327,240.8	.4273	.4006	.8279
	249		2722.72	527.0	23,442,174.5	2,826,850.5	233,042.8	.5972	.1118	.7091	1,654,741.7	1,478,925.4	.3613	.4399	.8013
	250		3036.88	523.2	23,786,912.3	2,826,850.5	213,737.5	.5792	.0989	.6782	1,861,584.4	1,456,517.5	.3645	.4258	.7903
	251			533.2	22,925,067.7	2,895,798.0	212,358.5	.5800	.1015	.6816	2,192,532.8	1,430,662.1	.3890	.4021	.7912
	252			533.2	22,063,223.0	2,799,271.4	193,053.2	.5541	.0961	.6502	2,075,321.9	1,344,477.7	.3890	.3738	.7629
	253			505.4	22,752,698.8	2,833,745.2	213,737.5	.5986	.1018	.7005	2,233,901.3	1,409,977.8	.4183	.4093	.8276
	254			533.2	23,959,281.3	2,930,271.8	220,632.2	.5908	.1015	.6924	2,220,111.8	1,447,899.0	.3970	.4006	.7977
	255			533.2	23,097,436.6	2,957,850.8	227,527.0	.5865	.1074	.6940	2,061,532.4	1,444,451.6	.3966	.4163	.8129

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M^2	PUMP END SEAL PR DRAIN N/M^2	PUMP END SEAL SEC DRAIN N/M^2	PUMP END SEAL LEAKAGE KG/SEC PRI	PUMP END SEAL LEAKAGE KG/SEC SEC	PUMP END SEAL LEAKAGE KG/SEC TOTAL	TURBINE END SEAL PRI DRAIN N/M^2	TURBINE END SEAL SEC DRAIN N/M^2	TURBINE END SEAL LEAKAGE KG/SEC PRI	TURBINE END SEAL LEAKAGE KG/SEC SEC	TURBINE END SEAL LEAKAGE KG/SEC TOTAL
14 (CONT.)	256	2.5	3036.88	533.2	23,442,174.5	2,957,850.8	230,974.4	.6035	.1040	.7076	2,192,532.8	1,482,372.8	.3975	.4203	.8161
	257			516.5	23,786,912.3	2,895,798.0	234,421.7	.5939	.1088	.7027	1,792,636.9	1,465,135.9	.3969	.4086	.8055
	258			526.5	24,821.125.9	2,826,850.8	220,632.2	.5853	.1081	.6934	2,206,322.3	1,572,004.6	.3733	.4576	.8309
	259			533.2	23,959.281.3	2,999,219.4	243,385.0	.6341	.1079	.7110	2,047,742.9	1,516,846.6	.3797	.4432	.8229
	260			533.2	23,717,964.8	2,871,666.4	213,737.5	.5904	.1055	.6960	2,061,532.4	1,551,320.4	.3826	.3871	.7697
	261			527.0	23,786,912.3	2,981,982.5	227,527.0	.6031	.1112	.7235	2,068,427.2	1,536,530.9	.3828	.4500	.8328
	262			533.2	23,649,017.2	2,964,745.6	232,353.3	.5982	.1133	.7115	2,137,374.7	1,503,057.1	.3917	.4862	.8780
	263			520.4	23,442,174.5	2,999,219.4	241,316.5	.6017	.1094	.7111	2,109,795.7	1,485,820.2	.3804	.4357	.8161
	264			528.2	24,131,650.2	2,888,903.3	241,316.5	.6078	.1133	.7212	2,192,532.8	1,465,135.9	.4027	.4367	.8395
	265			533.2	23,614,543.4	3,033,693.2	220,632.2	.5878	.1076	.6955	2,199,427.5	1,465,135.9	.3869	.4095	.7965
	266			530.9	23,442,174.5	3,050,930.1	227,527.0	.5837	.1050	.6888	2,116,690.5	1,485,820.2	.3785	.4267	.8053
	267			510.4	23,442,174.5	2,964,745.6	244,764.0	.6038	.1130	.7169	2,206,322.3	1,485,820.2	.4087	.4397	.8484
	268			533.2	23,786,912.3	2,971,640.4	234,421.7	.5084	.1077	.6881	2,137,374.7	1,447,899.0	.3963	.4112	.8074
	269			504.3	22,752,698.8	2,930,271.8	233,042.8	.5825	.1058	.6884	2,054,637.6	1,477,899.0	.3860	.4344	.8205
	270			532.6	23,442,174.5	2,930,271.8	228,906.0	.5751	.1034	.6785	2,068,427.2	1,447,899.0	.3829	.4073	.7903
	271			528.7	23,786,912.3	2,895,798.0	239,937.6	.6038	.1114	.7153	2,102,900.9	1,375,504.1	.3860	.4098	.7958
	272			533.2	23,959,281.3	3,033,693.2	222,700.7	.6075	.1078	.7154	2,206,322.3	1,465,135.9	.3729	.4198	.7928
	273			527.0	23,442,174.5	3,040,587.9	229,595.4	.6322	.1150	.7472	2,206,322.3	1,447,899.0	.4251	.4380	.8631
	274			533.2	23,511,122.1	3,050,930.1	239,937.6	.6094	.1108	.7203	2,206,322.3	1,444,451.7	.3987	.4213	.8200
	275			533.2	23,442,174.5	2,981,982.5	220,632.2	.5908	.1050	.6958	2,206,322.3	1,378,951.5	.4138	.3878	.8016
	276			531.5	23,614,543.4	2,999,219.4	226,148.0	.6028	.1064	.7093	2,206,322.3	1,416,872.6	.4191	.4038	.8229
	277			528.2	23,717,964.8	2,999,219.4	222,011.2	.5979	.1077	.7056	2,185,638.0	1,444,451.7	.3894	.4263	.8158
	278			533.2	23,786,912.3	3,033,693.2	248,211.3	.6128	.1144	.7273	2,075,321.9	1,485,820.2	.4007	.4439	.8446
15	279			527.0	23,097,436.6	465,396.1	193,053.2	.5796	.0988	.6785	2,240,796.1	1,146,598.1	.4430	.3520	.7951
	280		3120.656	528.2	24,752,178.4	1,492,714.9	220,632.2	.6073	.1096	.7171	2,206,322.3	1,396,188.3	.3609	.4006	.7615
	281		3036.88	533.2	24,269,545.3	2,413,165.0	210,290.1	.6268	.1033	.7302	2,468,323.1	1,278,977.5	.4554	.3689	.8241
	282			533.2	23,683,491.0	2,420.059.8	206,842.7	.6150	.1008	.7157	2,330,427.9	1,430,662.1	.3954	.3942	.7897
	283			533.2	23,993,755.1	2,206,322.3	208,911.1	.6150	.1031	.7180	2,468,323.1	1,241,056.3	.4243	.3619	.7860
	284			528.2	24,131,650.2	2,033,953.4	220,632.2	.6223	.1048	.7271	2,447,638.8	1,298,282.8	.4398	.3841	.8241
	285			533.2	24,131,650.2	2,275,269.9	206,153.2	.6109	.0982	.7094	2,516,586.4	1,275,530.1	.4364	.3681	.8046
	286			519.3	23,959,281.3	1,799,531.6	219,253.3	.6073	.1043	.7116	2,137,374.7	1,444,451.6	.3791	.4245	.8037
	287			533.2	24,131,650.2	2,354,559.6	206,842.7	.6050	.1001	.7053	2,344,217.4	1,513,399.2	.4150	.3844	.7996
	288			500.7	23,442,174.5	2,378,691.2	220,632.2	.6173	.1063	.7239	1,551,320.4	1,620,267.9	.3491	.4783	.8273
	289			495.1	23,786,912.3	1,940,874.2	210,290.1	.6182	.1066	.7248	1,378,951.4	1,723,689.3	.3084	.5180	.8264

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M^2	PUMP END SEAL PR DRAIN N/M^2	PUMP END SEAL SEC DRAIN N/M^2	PUMP END SEAL LEAKAGE KG/SEC PRI	PUMP END SEAL LEAKAGE KG/SEC SEC	PUMP END SEAL LEAKAGE KG/SEC TOTAL	TURBINE END SEAL PRI DRAIN N/M^2	TURBINE END SEAL SEC DRAIN N/M^2	TURBINE END SEAL LEAKAGE KG/SEC PRI	TURBINE END SEAL LEAKAGE KG/SEC SEC	TURBINE END SEAL LEAKAGE KG/SEC TOTAL
15 (CONT.)	290	2.5	3036.88	533.2	23,786,912.3	2,275,269.9	205,463.8	.5978	.1040	.7017	2,309,743.7	1,344,477.7	.3968	.3835	.7806
	291			533.2	22,959,541.5	2,344,217.4	206,842.7	.5860	.1023	.6885	1,378,951.4	1,723,689.3	.4128	.4862	.8990
	292				24,131,650.2	1,927,084.6	234,421.7	.5793	.1129	.7103	1,447,899.0	1,758,163.1	.4177	.5102	.9280
	293				24,269,545.3	1,737,478.8	221,321.7	.6037	.1113	.7153	2,344,217.4	1,372,056.7	.4022	.4086	.8110
	294				23,786,912.3	2,268,375.1	213,737.5	.5919	.1036	.6958	1,516,846.6	1,654,741.7	.4327	.4703	.9035
	295				22,407,960.9	2,320,085.8	196,500.6	.5506	.0979	.6486	1,813,321.1	1,534,083.5	.2967	.4282	.7248
	296			522.0	24,131,650.2	1,689,216.0	213,737.5	.5778	.1052	.6831	1,930,532.0	1,603,031.0	.2936	.4740	.7674
	297			533.2	23,442,174.5	2,351,112.2	213,737.5	.5805	.1020	.6826	1,585,794.2	1,716,794.5	.2901	.4880	.7783
16	298			530.9	26,027,708.4	1,137,634.9	235,800.7	.6128	.1182	.7311	1,516,846.6	275,790.3	.5597	.1110	.6708
	299			533.2	25,510,601.6	2,757,902.9	213,737.5	.6082	.1056	.7139	1,551,320.4	275,790.3	.5715	.1044	.6758
	300			533.2	26,200,077.4	2,551,060.2	206,842.7	.6218	.1060	.7280	1,585,794.2	293,027.2	.5978	.1210	.7189
	301			533.2	25,338,232.7	999,739.8	272,342.9	.6223	.1189	.7411	1,599,583.7	310,264.1	.6091	.1076	.7166
	PRE 302 STATIC		0	355.4	2,757,902.9	275,790.3	5,515.8	.5438	.0394	.1297	268,895.5	17,236.9	.0912	.0367	.1279
			0	342.8	6,894,757.2	768,765.4	28,958.0	.2390	.0476	.2866	551,580.6	34,473.8	.2425	.0385	.2812
			0	335.9	10,342,135.8	1,172,108.7	68,947.6	.3683	.0571	.4254	827,370.9	95,147.6	.3733	.0517	.4250
			0	308.2	13,789,514.4	1,689,215.5	124,105.6	.5057	.0715	.5774	1,034,213.6	172,369.0	.5347	.0821	.6168
			0	294.3	17,236,893.0	2,154,611.6	193,053.2	.6817	.1025	.7842	1,378,951.4	258,553.4	.7130	.1145	.8278
	302		3036.88	533.2	26,200.077.4	2,792,376.7	220,632.2	.6227	.0960	.7189	1,654,741.7	275,790.3	.6059	.0939	.6998
	303				26,200,077.4	2,792,376.6	220,632.2	.6082	.0988	.7071	1,620,268.0	298,543.0	.6032	.0957	.6989
	304				25,510,601.4	2,661,324.2	217,185.0	.6173	.0970	.7144	1,654,741.7	258,533.4	.6073	.0863	.6935
	305				25,510,601.4	2,706,192.2	220,632.2	.6082	.0987	.7071	1,654,741.7	258,533.4	.6132	.0927	.7057
	306				24,821,125.9	2,309,743.7	206,843.0	.5756	.0930	.6685	1,572,004.6	272,342.9	.5932	.0946	.6880
	307				25,372,707.0	2,544,165.4	213,738.0	.6028	.0956	.6985	1,620,268.0	258,533.4	.6059	.0889	.6949
	308				24,131,650.2	2,744.113.4	195,811.1	.5864	.0984	.6758	1,585,794.1	227,527.0	.5946	.0805	.6753
	309			518.4	24,821,125.9	1,896,058.2	233,043.0	.6118	.1042	.7162	1,530,636.1	298,543.0	.6132	.1095	.7230
	310			533.2	26,200.077.4	2,282,164.6	233,043.0	.6291	.1065	.7357	1,640,952.2	244,764.0	.6223	.0969	.7193
	311				25,510,601.6	2,482,112.6	206,843.0	.6010	.0970	.6980	1,654,741.7	241,317.0	.6137	.0815	.6953
	312				25,510,601.6	2,336,322.7	220,632.2	.6105	.0998	.7130	1,654,741.7	246,832.3	.6200	.0915	.7116
	313				25,855,340.0	2,033,953.4	227,527.0	.6250	.1061	.7311	1,654,741.7	277,859.0	.6227	.1016	.7243
	314				25,510,601.6	2,344,217.4	206,153.2	.6014	.0971	.6985	,740,952.2	241,317.0	.6137	.0871	.7008
	315				24,821,126.0	2,757,903.0	189,606.0	.5955	.0908	.6862	1,654,741.7	220,632.2	.5833	.0795	.6626
	316				25,510,601.6	1,965,006.0	220,632.2	.6236	.1022	.7262	1,640,952.2	275,790.3	.5892	.1072	.6962
	317				25,510,601.6	2,716,534.3	206,843.0	.6059	.0949	.7008	1,654,741.7	229,595.4	.5892	.0868	.6765
	318				24,821,126.0	2,516,586.4	124,106.0	.5937	.0913	.6849	1,585,794.2	241,317.0	.5565	.0920	.6486

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M^2	PUMP END SEAL PR DRAIN N/M^2	SEC DRAIN N/M^2	LEAKAGE KG/SEC PRI	SEC	TOTAL	TURBINE END SEAL PRI DRAIN N/M^2	SEC DRAIN N/M^2	LEAKAGE KG/SEC PRI	SEC	TOTAL
16 (CONT)	319	2.5	3036.88	533.2	25,510,601.6	2,482,112.6	199,948.0	.6109	.0967	.7076	1,654,741.7	272,343.0	.5765	.1018	.6785
	320			533.2	25,510,601.6	2,482,112.6	262,000.8	.6001	.0910	.6912	1,585,794.2	275,790.3	.5770	.1016	.6586
	321			528.7	25,338,232.7	1,737,479.0	206,842.7	.6014	.0974	.6989	1,516,846.6	275,790.3	.5770	.1016	.6586
	322			533.2	25,510,601.6	2,344,217.4	234,421.7	.5942	.0900	.6844	1,516,846.6	210,290.1	.5715	.0830	.6545
	323			522.0	25,510,601.6	1,758,163.1	233,043.0	.6268	.1098	.7366	1,530,636.1	293,027.2	.6214	.1119	.7334
	324			529.8	24,993,495.0	1,868,479.2	217,185.0	.6082	.1041	.7125	1,537,530.9	279,237.7	.6023	.1091	.7116
	325			405.4	25,510,601.6	1,671,978.6	220,632.2	.6304	.1094	.7398	1,585,794.2	313,711.5	.6177	.1668	.7348
	326			533.2	25,165,863.8	1,958,111.0	199,948.0	.6105	.1036	.7144	1,585,794.2	306,816.7	.5978	.1070	.7048
	327				25,165,863.8	2,888,903.3	251,658.6	.6114	.0935	.7048	1,654,741.7	258,553.4	.6073	.0831	.6903
	328				25,510,601.6	2,446,638.8	193,948.0	.6186	.0966	.7153	1,585,794.2	310,264.1	.6118	.1055	.7175
	329				25,510,601.6	2,282,164.6	195,811.1	.6128	.0973	.7103	1,544,425.6	327,501.0	.6041	.1122	.7166
	330				25,510,601.6	2,206,322.3	197,190.1	.6168	.0983	.7153	1,551,320.4	324,053.6	.6032	.1131	.7166
	331				25,855,334.0	2,271,822.5	193,053.2	.1686	.0974	.7162	1,585,794.2	336,464.2	.6010	.1143	.7153
	332			531.5	25,510,601.6	1,792,637.0	205,463.8	.6005	.0990	.6994	1,516,846.6	344,737.9	.5851	.1202	.7053
	333			533.2	25,855,334.0	1,940,948.0	199,948.0	.6173	.0957	.7130	1,516,846.6	351,632.6	.5914	.1186	.7103
	334			533.2	25,682,970.6	2,547,162.8	151,684.7	.6218	.0888	.7112	1,516,846.6	310,264.1	.5910	.1073	.6985
	335			527.3	25,682,970.6	1,430,662.1	201,326.9	.6418	.1013	.7434	1,585,794.2	367,490.6	.6341	.1270	.7611
	336			530.4	25,510,601.6	1,758,163.1	211,669.0	.6286	.1031	.7320	1,562,004.6	344,737.9	.6214	.1157	.7370
	337			522.0	25,362,706.5	2,206,322.3	251,658.6	.6368	.0988	.7357	1,551,320.4	351,632.6	.6196	.1184	.7379
	338			533.2	24,821,126.0	2,247,690.8	234,421.7	.6046	.0869	.6917	1,516,846.6	310,264.1	.5969	.1032	.7003
	339			510.4	25,165,863.8	1,689,215.5	206,498.0	.6341	.1031	.7370	1,516,846.6	375,764.3	.6196	.1206	.7402
	340			533.2	24,821,126.0	2,826,850.5	172,369.0	.6087	.0878	.6967	1,516,846.6	313,711.5	.5923	.1003	.6926
	341				25,165,863.8	2,544,165.4	179,263.7	.6218	.0909	.7130	1,516,846.6	344,737.9	.6177	.1161	.7339
	342				24,821,126.0	2,240,796.1	165,474.2	.6055	.0894	.6949	1,516,846.6	327,501.0	.6118	.1157	.7275
	343			510.9	25,165,863.8	1,913,295.1	193,053.2	.6386	.0979	.7366	1,516,846.6	344,738.0	.6314	.1319	.7633
	344				25,855,340.0	2,171,848.5	137,895.1	.5424	.0775	.6200	1,365,161.9	241,316.5	.5420	.1013	.6431
	345				24,821,126.0	2,682,060.6	166,853.1	.6082	.0891	.6976	1,516,846.6	296,474.6	.6087	.1107	.7193
	346				25,165,863.8	2,533,823.3	164,784.7	.6146	.0864	.7012	1,516,846.6	301,990.4	.6105	.1148	.7252
	347				26,027,708.4	2,351,112.2	165,474.2	.6223	.0933	.7157	1,516,846.6	336,464.2	.5765	.1137	.6903
	348				24,821,126.0	2,533.823.3	193,053.[illegible]	.6200	.0983	.7184	1,754,741.6	379,211.6	.6091	.1172	.7262
	349			527.6	24683,230.8	2,950,956.1	206,842.7	.6226	.1081	.7311	1,634,057.5	379,211.6	.5837	.1226	.7062
	350			523.4	24,131,650.2	2,930,271.8	199,948.0	.6023	.1036	.7062	1,551,320.4	358,527.4	.6010	.1255	.7266
	351			528.7	24,821,126.0	2,771,692.4	215,116.4	.6073	.1099	.7175	1,530,636.1	379,211.6	.6128	.1268	.7398
	352			518.7	24,131,650.2	2,875,113.8	198,569.0	.5955	.0987	.6944	1,530,636.1	379,211.6	.6010	.1239	.7248

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M^2	PUMP END SEAL PR DRAIN N/M^2	PUMP END SEAL SEC DRAIN N/M^2	PUMP END SEAL LEAKAGE KG/SEC PRI	PUMP END SEAL LEAKAGE KG/SEC SEC	PUMP END SEAL LEAKAGE KG/SEC TOTAL	TURBINE END SEAL PRI DRAIN N/M^2	TURBINE END SEAL SEC DRAIN N/M^2	TURBINE END SEAL LEAKAGE KG/SEC PRI	TURBINE END SEAL LEAKAGE KG/SEC SEC	TURBINE END SEAL LEAKAGE KG/SEC TOTAL
16	353	2.5	3036.88	533.2	24,131,650.2	2,882,008.5	182,711.0	.5751	.0962	.6713	1,585,794.2	344,737.9	.6037	.1089	.7125
(CONT.)	354			523.4	24,890,073.5	2,847,534.7	217,185.0	.6177	.1037	.7216	1,585,794.2	410,238.1	.6382	.1311	.7692
	355			533.2	24,131,650.2	2,895,798.0	180,642.6	.5805	.0978	.6785	1,516,846.6	375,764.3	.6019	.1171	.7189
	356			528.7	25,338,233.0	2,882,008.5	213,737.5	.6105	.1080	.7184	1,640,962.2	413,685.4	.6209	.1311	.7520
	357			506.8	25,510,601.6	2,875,113.8	217,185.0	.6232	.1035	.7266	1,640,952.2	244,764.0	.6314	.0910	.7679
17	358			527.6	24,131,650.2	2,620,007.7	274,411.3	.5928	.1392	.7320	1,516,846.6	244,764.0	.5783	.0848	.6631
	359			533.2	24,131,650.2	2,675,165.8	289,579.8	.5837	.1342	.7180	1,523,741.3	244,764.0	.5665	.0902	.6568
	360			528.2	23,786,912.3	2,688,955.3	317,158.8	.6091	.1369	.7461	1,516,846.6	310,264.1	.5606	.1211	.6817
	361			533.2	24,476,388.1	2,675,165.8	303,369.3	.5833	.0893	.7180	1,551,320.4	241,316.5	.5515	.0911	.6427
	362			533.2	24,028,228.8	2,626,902.5	301,990.4	.5946	.1356	.7302	1,516,846.6	279,237.7	.5511	.1056	.6568
	363			533.2	24,200,597.8	2,737,218.6	310,264.1	.6010	.1387	.7398	1,516,846.6	250,279.7	.5620	.0957	.6577
	364			521.5	24,131,650.2	2,688,955.3	317,158.8	.6123	.1397	.7520	1,516,846.6	275,790.3	.5551	.1025	.6577
	365			533.2	24,131,650.2	2,688,955.3	324,053.6	.5951	.1387	.7339	1,530,636.1	241,316.5	.5397	.0902	.6300
	366				23,590,069.2	2,702,744.8	330,948.3	.5851	.1369	.7221	1,516,846.6	255,106.0	.5148	.0957	.6105
	367				24,131,650.2	2,613,113.0	296,474.6	.5756	.1301	.7057	1,482,372.8	248,211.3	.5238	.0943	.6182
	368				23,442,174.5	2,613,113.0	358,527.4	.5701	.1333	.7032	1,516,846.6	234,421.7	.5429	.0843	.6273
	369				23,304,279.3	2,654,481.5	358,527.4	.5656	.1338	.6994	1,509,951.8	241,317.0	.5456	.0920	.6377
	370				23,442,174.5	2,633,797.3	351,632.6	.5737	.1369	.7107	1,516,846.6	248,211.3	.5474	.0938	.6413
	371				23,649,017.2	2,633,797.3	317,158.6	.5742	.1342	.7085	1,461,688.5	255,106.0	.5424	.0943	.6368
	372				23,580,070.0	2,564,849.7	344,738.0	.5756	.1347	.7103	1,503,057.1	282,685.0	.5443	.1020	.6459
	373				23,511,27 .1	2,620,007.7	303,369.3	.5719	.1347	.7066	1,461,688.5	255,106.0	.5406	.0943	.6350
	374				23,442,174.5	2,585,534.0	289,579.8	.5747	.1265	.7012	1,516,846.6	268,895.5	.5483	.0961	.6445
	375				22,990,593.9	2,599,323.5	296,474.6	.5497	.1306	.6803	1,551,320.4	241,316.5	.5502	.0911	.6413
	376				23,304,279.3	2,544,165.4	303,369.3	.5588	.1342	.6930	1,572,004.6	282,685.0	.5452	.1065	.0651
	377				23,442,174.5	2,585,534.0	296,474.6	.5583	.1315	.6899	1,551,320.4	268,895.5	.5629	.1016	.6645
	378				23,373,226.9	2,551,060.2	296,474.6	.5633	.1315	.6949	1,537,530.9	289,579.8	.5629	.1061	.6690
	379				22,683,751.2	2,551,060.2	296,474.6	.5579	.1342	.6921	1,516,846.6	275,790.3	.5483	.1084	.6568
	390				23,442,174.5	2,688,955.3	289,579.8	.5715	.1297	.7012	1,482,372.8	317,158.8	.5220	.6386	
	381				23,442,174.5	2,633,797.3	317,158.8	.5769	.1347	.7116	1,516,846.6	344,737.9	.5438	.1183	.6622
	382				22,545,856.0	2,688,955.3	303,369.3	.5529	.1310	.6840	1,503,057.0	275,790.3	.5161	.1011	.6173
	383				23,373,226.9	2,688,955.3	303,369.3	.5706	.1365	.7071	1,516,846.6	310,264.1	.5329	.1065	.6395
	384				22,890,593.9	2,654,481.5	324,053.6	.5669	.1333	.7003	1,482,372.8	282,685.0	.4971	.1011	.5982
	385				23,304,279.3	2,695,850.1	317,158.8	.5701	.1360	.7062	1,516,846.6	303,369.3	.4939	.1061	.6001
	386				23,442,174.5	2,695,850.1	317,158.8	.5706	.1356	.7062	1,551,320.4	317,158.8	.4971	.1115	.6087

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M^2	PUMP END SEAL PR DRAIN N/M^2	SEC DRAIN N/M^2	LEAKAGE KG/SEC PRI	SEC	TOTAL	TURBINE END SEAL PRI DRAIN N/M^2	SEC DRAIN N/M^2	LEAKAGE KG/SEC PRI	SEC	TOTAL
17 (CONT.)	387	2.5	3036.88	533.2	23,097,436.6	2,654,481.5	296,474.6	.5683	.1288	.6971	1,496,162.3	310,264.1	.5216	.1079	.6295
	388				23,649,017.2	2,654,481.5	317,158.8	.5828	.1369	.7198	1,516,846.6	344,737.9	.5311	.1220	.6531
	389				23,442,174.5	2,533,797.3	317,158.8	.5824	.1351	.7175	1,447,899.0	344,737.9	.5293	.1233	.6527
	390				23,373,226.9	2,633,797.3	310,264.1	.5724	.1347	.7071	1,516,846.6	317,158.8	.5180	.1147	.6327
	391				22,959,541.5	2,654,481.5	303,369.3	.5556	.1333	.6890	1,516,846.6	317,158.8	.5180	.1143	.6323
	392				23,097,436.6	2,688,955.3	317,158.8	.5697	.1342	.7039	1,516,846.6	310,264.1	.5175	.1147	.6323
	393				23,580,069.6	2,620,007.7	310,264.1	.5824	.1347	.7171	1,496,162.3	351,632.6	.5148	.1288	.6436
	394			530.4	23,442,174.5	2,688,955.3	317,158.8	.5778	.1401	.7180	1,378,951.4	330,948.3	.5175	.1211	.6386
	395			533.2	22,959,541.5	2,640,692.0	317,158.8	.5647	.1360	.7008	1,516,846.6	310,264.1	.5143	.1102	.6245
	396			526.5	24,476,388.1	2,688,955.3	296,474.6	.5828	.1360	.7189	1,378,951.4	337,843.1	.4889	.1233	.6123
	397			533.2	24,131,650.2	2,723,429.1	306,816.7	.5796	.1401	.7198	1,482,372.8	379,211.6	.5007	.1292	.6300
	398			532.0	24,476,388.1	2,702,744.8	304,748.3	.5842	.1401	.7243	1,447,899.0	393,001.2	.5034	.1301	.6336
	399			533.2	24,131,650.2	2,675,165.8	299,921.9	.5710	.1356	.7066	1,503,057.1	393,001.2	.4980	.1274	.6255
	400				23,442,174.5	2,688,955.3	317,158.8	.5624	.1347	.6971	1,516,846.6	358,527.4	.4966	.1197	.5710
	401				23,442,174.5	2,620,007.7	310,264.1	.5424	.1238	.6663	1,516,846.6	358,527.4	.5402	.1179	.6581
	402				22,063,223.0	2,551,060.2	303,369.3	.5352	.1202	.6554	1,503,057.1	344,737.9	.5329	.1124	.6454
	403				22,407,961.0	2,551,060.2	310,264.1	.5434	.1220	.6654	1,482,372.8	379,211.6	.5307	.1224	.6531
	404				22,063,223.0	2,599,323.5	303,369.3	.5452	.1224	.6676	1,516,846.6	372,316.9	.5220	.1188	.6409
	405				23,442,174.8	2,620,007.7	317,158.8	.5778	.1301	.7080	1,516,846.6	441,264.5	.5388	.1374	.6763
	406			527.6	23,959,281.3	2,640,692.0	332,327.3	.5987	.1369	.7357	1,516,846.6	468,843.5	.5365	.1537	.6903
	407			533.2	23,442,174.5	2,613,113.0	317,158.8	.5895	.1324	.7130	1,516,846.6	461,948.7	.5443	.1465	.6908
	408				23,442,174.5	2,585,534.0	313,711.5	.5810	.1288	.7098	1,516,846.6	461,948.7	.5561	.1460	.7021
	409				22,407,960.9	2,551,060.2	318,537.8	.5456	.1251	.6708	1,516,846.6	365,422.1	.5429	.1224	.6654
	410				22,580,329.8	2,564,849.[illegible]	310,264.1	.5538	.1247	.6785	1,503,057.1	434,369.7	.5370	.1351	.6722
	411				22,752,698.8	2,613,113.0	330,948.3	.5547	.1265	.6812	1,516,846.6	393,001.2	.5597	.1229	.6826
	412				24,131,650.2	2,551,060.2	316,469.4	.5783	.1360	.7144	1,061,792.6	461,948.7	.5252	.1505	.6758
	413			530.4	21,718,485.2	2,530,375.9	295,09[illegible].6	.5225	.1192	.6418	1,447,899.0	344,737.9	.4889	.1002	.5892
	414			533.2	21,373,747.3	2,482,112.6	289,579.8	.5266	.1220	.6486	1,503,057.1	379,211.6	.5116	.1220	.6336
	415				22,407,960.9	2,557,955.0	315,779.9	.5474	.1274	.6749	1,516,846.6	379,211.6	.4948	.1233	.6182
	416				22,925,067.7	2,606,218.2	313,711.5	.5561	.1297	.6858	1,516,846.6	448,159.2	.4953	.1401	.6354
	417				22,235,592.0	2,551,060.2	317,158.8	.5370	.1251	.7076	1,516,846.6	399,895.9	.4912	.1206	.6118
18	418				22,235,592.0	2,606,218.2	304,748.3	.5520	.1268	.6788	1,378,951.4	434,369.7	.4994	.1487	.6481
	419				22,752,698.8	2,413,165.0	317,158.8	.5624	.1331	.6955	1,378,951.4	434,369.7	.4808	.1397	.6205
	420				22,063,223.0	2,537,270.7	303,369.3	.5547	.1295	.6842	1,378,951.4	455,053.9	.5057	.1514	.6572

TABLE 13. (Continued)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M^2	PUMP END SEAL					TURBINE END SEAL				
						PR DRAIN N/M^2	SEC DRAIN N/M^2	LEAKAGE KG/SEC			PRI DRAIN N/M^2	SEC DRAIN N/M^2	LEAKAGE KG/SEC		
								PRI	SEC	TOTAL			PRI	SEC	TOTAL
18	421	2.5	3036.88	533.2	21,373.747.3	2,551,060.3	318,537.8	.5373	.1327	.6706	1,447,899.0	379,211.6	.5066	.1247	.6314
19	422				22,752,698.8	2,723,429.1	289,579.8	.5737	.2178	.7916	1,434,109.5	496,422.5	.5184	.1446	.6631
	423				22,235,592.0	2,695,850.1	296,474.6	.5724	.2240	.7964	1,447,899.0	427,474.9	.5071	.1342	.6413
	424				21,890,854.1	2,626,902.5	289,579.8	.5570	.2187	.7751	1,434,109.5	482,633.0	.5007	.1315	.6323
	425				22,925,067.7	2 [illegible] 166.6	317,158.8	.5747	.1319	.7203	1,516,846.6	448,159.2	.5338	.1365	.6704
	426			530.4	23,442,174.5	2,[illegible],902.9	317,158.8	.6100	.1388	.7488	1,482,372.8	496,422.5	.5334	.1655	.6989
	427			533.2	22,407,960.9	2,757,902.9	315,779.9	.5801	.1337	.7139	1,516,846.6	413,685.4	.5325	.1387	.6713
	428			499.8	22,925,067.7	2,688,955.3	310,264.1	.6128	.1390	.7518	1,413,425.2	496,422.5	.5393	.1723	.7116
	429			533.2	22,683,751.2	2,682,060.6	303,369.3	.5833	.1310	.7144	1,447,899.0	441,264.6	.5229	.1496	.6726
	430			533.2	22,407,960.9	2,744,113.4	317,158.8	.5828	.1345	.7174	1,496,162.3	427,474.9	.5198	.1483	.6717
	433			533.2	22,752,698.8	2,654,481.5	303,369.3	.5669	.1319	.6988	1,378,951.4	482,633.0	.5007	.1469	.6477
	434			533.2	22,407,960.9	2,688,955.3	303,369.3	.5724	.1329	.7054	1,447,889.0	427,474.9	.5216	.1306	.6522
	435			533.2	22,235,592.0	2,633,797.3	303,369.3	.5706	.1321	.7027	1,378,951.4	420,580.2	.5016	.5914	.6395
	436			524.8	22,752,698.8	2,585,533.6	303,369.3	.5846	.1334	.7181	1,275,530.1	448,159.2	.4930	.1546	.6477
	437			508.2	22,925,067.7	2,620,007.7	282,685.0				1,310,003.8	496,422,5			
	438			520.9	23,442,174.8	2,757,902.9	282,685.0				1,378,951.4	482,633.0			
20	439			533.2	22,407,960.9	2,792,376.7	330,948.3				1,378,951.4	337,843.1			
	440			533.2	22,235,592.0	2,709,639.6	262,000.8				1,378,951.4	310,264 1			
	441			533.2	23,442,174.5	2,826,850.5	268,895.5				1,392,741.0	351,632.6-			
	442			528.7	24,131,650.2	2,826,850.5	262,000.7				1,378,951.4	351,632.6			
	443			533.2	22,063,323.0	2,688,955.3	262,000.7				1,275,530.1	262,000.8			
	444			526.5	24,131,650.2	2,757,902.9	255,106.0	*	*	*	1,365,161.9	393,001.2	*	*	*
	445			533.2	24,476,388.1	2,757,902.9	289,579,8				1,516,846.6	365,422.1			
	446			533.2	24,131,650.2	2,723,429.1	275,790.3				1,434,109.5	358,527.4			
	447			510.9	24,131,650.2	2,620,007.7	289,579.8				1,344,477.7	337,843.1			
	448			533.2	23,442,174.5	2,792,376.7	289,579.8				1,482,372.8	330,948.3			
	449			533.2	24,476,388.1	2,654,481.5	296,474.6				1,378,951.4	337,843.1			
	450			533.2	22,752,698.8	2,688,955.3	268,895.5				1,378,951.4	337,843.1			
	451			533.2	24,131,650.2	2,6]0,007.7	268,895.5				1,365,161.9	379,211.6			
	452			533.2	24,131,650.2	2,757,902.9	282,685.0				1,378,951.4	358,527.4			
	453			524.8	24,131,650.2	2,688,955.3	282.650.0				1,447,899.0	379,211.6			
	454			533.2	24,131,650.2	2,861,324.2	289,579.8				1,413,425.2	365,422.1			
	455			528.7	24,131,650.2	2,757,902.9	289,579.8				1,344,477.7	344,737.9			
	456			533.2	23,614,545.4	2,620,007.7	289,579.8				337,843.1	1,358,267.2			

*INSTRUMENTATION PROBLEM - INVALIDATED DATA

TABLE 13. (Concluded)

BUILD NO.	TEST NO.	TIME MIN.	SPEED RAD/SEC	INLET TEMP, K	INLET PR N/M^2	PUMP END SEAL PR DRAIN N/M^2	PUMP END SEAL SEC DRAIN N/M^2	PUMP END SEAL LEAKAGE KG/SEC PRI	PUMP END SEAL LEAKAGE KG/SEC SEC	PUMP END SEAL LEAKAGE KG/SEC TOTAL	TURBINE END SEAL PRI DRAIN N/M^2	TURBINE END SEAL SEC DRAIN N/M^2	TURBINE END SEAL LEAKAGE KG/SEC PRI	TURBINE END SEAL LEAKAGE KG/SEC SEC	TURBINE END SEAL LEAKAGE KG/SEC TOTAL
20	457	2.5	3036.88	533.2	23,097,436.6	2,792,376.7	296.474.6	.5846	.1334	.7181	337,843.1	1,413,425.2	.4930	.1546	.6477
(CONT.)	458			533.2	23,097,436.6	2,757,902.9	275,790.3	*	*	*	337,843.1	1,413,425.2	*	*	*
	459			533.2	24,131,650.2	2,792,376.7	289,579.8	.5846	.1334	.7181	330,948.3	1,378,951.4	.4930	.1546	.6477
	460			533.2	23,442,174.5	2,930,271.8	330,948.3	.5914	.1422	.7339	420,580.2	1,447,899.0	.5134	.1342	.6477
	461			528.7	24,131,650.2	2,792,376.7	310,264.1	.6227	.1373	.7602	482,633.0	1,378,951.4	.5089	.1619	.6708
	462			533.2	22,752,698.8	2,826,850.5	317,158.8	.5955	.1388	.7343	455,054.0	1,482,372,8	.5102	.1483	.6586
	463			533.2	23,442,174.5	2,909,587.5	330,948.3	.6019	.1443	.7461	482,633.0	1,503,057.1	.5229	.1537	.6767
	464			533.2	22,925,067.7	2,895,798.0	337,843.1	.5905	.1427	.7334	455,054.0	1,516,846.6	.5189	.1514	.6704
	465			533.2	23,097,436.6	2,964,745.6	330,948.3	.5937	.1432	.7370	448,159.2	1,516,846.6	.5202	.1496	.6699
	466			533.2	23,097,436.6	2,964,745.6	317,158.8	.5919	.1386	.7307	441,264.5	1,516,846.6	.5198	.1474	.6672
	467			533.2	23,442,174.5	2,950,956.1	330,948.3	.5955	.1443	.7398	448,159.2	1,503,057.1	.5216	.1528	.6744
	468			533.2	23,442,174.5	3,019,903.7	324,053.6	.5955	.1376	.7330	434,369.7	1,482,372.8	.5111	.1492	.6604
	469			523.2	24,131,650.2	2,757,902.9	303,369.3	.6137	.1376	.7516	358,527.4	1,413,425.2	.5039	.1814	.6853
	470			533.2	24,131,650.2	2,826,850.5	317,158.8	.6041	.1389	.7429	468,843.5	1,447,899.0	.5470	.1651	.7121
	471			533.2	23,614,543.4	2,757,902.9	324,053.6	.6037	.1418	.7457	468,843.5	1,482,372.8	.5134	.1551	.6685
	472			533.2	24,131,650.2	2,757,902.9	337,843.1	.6082	.1470	.7552	482,633.0	1,503,057.1	.5184	.1623	.6808
	473			533.2	23,442,174.5	2,826,850.5	330,948.3	.5905	.1432	.7339	489,527.8	1,516,846.6	.5143	.1501	.6645
	474			533.2	24,131,650.2	2,861,324.2	330,948.3	.6055	.1427	.7484	468,843.5	1,516,846.6	.5229	.1610	.6840
	475			533.2	24,131,650.2	2,895,798.0	330,948.3	.6001	.1454	.7457	461,948.7	1,516,846.6	.5216	.1537	.6753
	476			533.2	23,786,912,3	2,964,745.6	330,948.3	.5982	.1443	.7425	455,053.9	1,516,846.6	.5202	.1505	.6708
	477			533.2	23,442,174.5	2,895,798.0	317,158.8	.5919	.1417	.7339	448,159.2	1,503,057.1	.5075	.1483	.6558

*INSTRUMENTATION PROBLEM - INVALIDATION DATA approximately .25 second. The transient runout during coast down was slighty higher .0002032 m (.008 in.) P-P on most tests.

RAYLEIGH STEP SEAL PRELIMINARY CHECKOUT TESTING

Build No. 1 Assembly

The tester was assembled with two seals utilizing Rayleigh step self acting lift pads, installed back to back, for the Schedule 1 Preliminary Checkout Test at 3351 rad/sec (32000 rpm). Seal ring diametral clearances at assembly are given in the Inspection summary (Table 8).

Tests 001 through 003

Test points 1 through 3 of the Schedule I Preliminary Checkout test series were performed using ambient temperature gaseous nitrogen at pressures of 1723689, 3447378, and 6894757 n/m^2 (250, 500, and 1000 psig). The seals were pressurized to the test level prior to start of rotation. The tester was accelerated to 3351 rad/sec (32000 rpm) in 10 seconds and run for 2.5 minutes. Total of 3 tests for 7.5 minutes were performed stable data were obtained on all three tests. The seal leakage varied with pressure as shown below:

TEST NO.	PRESSURE N/M^2(PSIG)	TURB. END SEAL KG/SEC(LB/SEC)		PUMP END SEAL KG/SEC(LB/SEC)	
		PRIMARY	SECONDARY	PRIMARY	SECONDARY
001	1654741(24.0)	.0548(.121)	.0190(.042)	.0480(.106)	.0385(.085)
002	3199167(464)	.0943(.208)	.1814(.040)	.0589(.130)	.0589(.089)
003	6687914(970)	.1428(.315)	.0190(.042)	.1043(.230)	.0430(.095)

Build 1 Disassembly

Inspection revealed that the seal rings had rubbed the mating ring sleeve and worn the carbon inside diameter. The seal ring diametral wear varied from .00001525 to .00005842 m (.0006 to .0023 in.). The inspection also revealed that the turbine end primary seal ring was installed backward which resulted in the lift pads facing the wrong direction relative to shaft rotation and reducing hydrodynamic lift. The post test 003 seal hardware and inspection data are tabulated in Tables 7 and 8. The lift pads were worn away on the turbine end seal primary ring and the pump end seal secondary ring.

The mating ring sleeve had a rub pattern with a deposit of carbon in the area of the seal ring. The tungsten carbide surface was in good condition with no measureable wear, except for one area at the pump end seal secondary ring. The surface was worn .00000635 m (.00025 in.) at the sealing dam location.

Build 2 Assembly

The tester was reassembled with the same seal hardware as Build 1 with no rework. The seal ring to shaft sleeve diametral clearances at assembly are given in Table 8 .

Tests 004 through 006

Test points 004 through 006 of the checkout test series were performed using ambient temperature gaseous nitrogen at pressure of 6894757, 10342135, and 13789514 n/m^2 (1000, 1500, and 2000 psig). The test procedure was changed to start the rotation at 344737 n/m^2 (50 psig) and increase the pressure to the test level after the tester was up to speed. The pressure was vented to 344737 n/m^2 (50 psig) prior to stopping the rotation.

Tests 004 and 005 were run at 3351 rad/sec (32000 rpm) for 2.5 minutes. Test 006 was cut at 1.75 minutes due to a speed drop. The total test time at steady speed was 6.75 minutes. The seal leakage varied with pressure as shown below:

TEST NO.	PRESSURE N/M^2(PSIG)	TURB. END SEAL KG/SEC(LB/SEC)		PUMP END SEAL KG/SEC(LB/SEC)	
		PRIMARY	SECONDARY	PRIMARY	SECONDARY
004	6618966 (760)	.1306(.288)	.0167(.037)	.0970(.214)	.0412(.091)
005	10135293(1470)	.2140(.472)	.0090(.020)	.1555(.343)	.0185(.041)
006	13444776(1950)	.2948(.650)	.0167(.037)	.2168(478)	.0117(.026)

Build 2 Disassembly Posttest 006

Inspection revealed that the seal rings had continued to rub the mating ring sleeve and wear the carbon inside diameter; however, the rate of wear decreased from the previous build. The seal ring diametral wear varied from .00000254 to .00004064 m (.001 to .0016 in.).

The lift pads showed slight additional wear above the wear sustained during Build 1 testing. The mating ring sleeve wore an additional .00000508 m (.0002 in.) at the pump end secondary seal ring. The surface was worn .00001143 m (.00045 in.) at the sealing dam location.

Build 3 Assembly Pretest 007

The tester was reassembled with the same seal hardware. The tester rotating parts were rebalanced at 34.4 and 733 rad/sec (300 and 7000 rpm).

Tests 007 through 009

Test points 007 through 009 of the Schedule 1 Preliminary Checkout test series were performed using ambient temperature gaseous nitrogen at pressures of 13789514, 17236893, and 20684271 n/m^2 (2000, 2500, and 3000 psig). The same test procedure was used. A total of three tests for 75 minutes were performed. Stable data were obtained on all three tests. The seal leakage varied with pressure as shown below:

TEST NO.	PRESSURE N/M^2 (PSIG)	TURB. END SEAL KG/SEC (LB/SEC)		PUMP END SEAL KG/SEC (LB/SEC)	
		PRIMARY	SECONDARY	PRIMARY	SECONDARY
007	13651619(1980)	.3048(.672)	.0195(.043)	.2431(.536)	.0290(.064)
008	17236893(2500)	.3941(869)	.0244(.054)	.3238(.714)	.0458(.101)
009	20684271(3000)	.4799(1.058)	.0385(.085)	.4318(.952)	.0657(.145)

Build 3 Disassembly Posttest 009

Inspection revealed the tester shaft sleeve had rubbed the seal housing. Pretest measurements indicated a .00042672 m (.0168 in.) radial clearance, while test data indicated a maximum radial displacement at the seal of .0004572 m (.018 in.). The seal ring diametral wear varied from .00001016 to .00002286 m (.0004 to .0009 in.) during Build 3.

The wear on the lift pads continued. The turbine end primary and secondary and the pump end secondary lift pads were worn away. The mating ring sleeve tungsten carbide plating was worn in the area of the seal rings from .00000127 to .00000889 in. (.00005 to .00035 in.). The amount of wear varied slightly around the sleeve.

Build 4 Assembly Pretest 10

The tester was reassembled with the same seal hardware. The rotating parts were rebalanced at 733 rad/sec (7000 rpm).

Tests 010 through 012

Test 010 was expected to run using ambient nitrogen gas at 20684271 n/m^2 (3000 psig). However, the maximum pressure obtained in the facility was 18615844 n/m^2 (2700 psig). The test was run for 2.5 minutes at steady state. This series completed Schedule I Preliminary Checkout testing.

The nitrogen gas pressure problem was reviewed and it was determined that at ambient temperature, the pressure could not be applied at greater than 22752698 n/m^2 (3300 psig). It was decided to run Test 011 at 20684271 n/m^2 (3000 psig) and test 012 at the maximum obtainable pressure. Test 011 was run at

20684271 n/m^2 (3000 psig) and test 012 at 22063223 n/m^2 (3200 psi) for 2.5 minutes. A total of 3 runs for 7.5 minutes was performed. The seal leakage varied with pressure as shown below:

TEST NO.	PRESSURE N/M^2 (PSIG)	TURB. END SEAL KG/SEC (LB/SEC)		PUMP END SEAL KG/SEC (LB/SEC)	
		PRIMARY	SECONDARY	PRIMARY	SECONDARY
010	18271106(2650)	.4472(.986)	.0358(.079)	.3996(.881)	.0585(.129)
011	20856640(3025)	.5279(1.164)	.0435(.096)	.4699(1.036)	.0771(.170)
012	22063223(3200)	.5579(1.230)	.0512(.113)	.4984(1.099)	.0802(.177)

Build 4 Disassembly Posttest 012

There was some erosion of the carbon seals at the leading edge of the sealing dam. The carbon seal diametral wear varied from 0 to .00000508 m (.0002 in.). The lift pads appeared to be completely worn away on all seal rings except for visible traces on the pump end primary seal ring. The mating ring sleeve wear in the pump end area was .00001397 m (.00055 in.). The seal hardware is shown in Fig. 33 through 37. The pump end primary seal surface profile trace is shown in Fig. 38 .

At this time, it was noticed that excessive radial displacement of the tester shaft during critical speed 1256 rad/sec (12000 rpm) transient is sufficient to cause the turbine end of the shaft to rub the seal housing. It also causes excessive seal wear and leakage. It is believed that improved balancing will reduce the radial displacement. Shaft rework is being considered. Radial diplacement measurements are shown in Table 14 .

Discussion - Builds 1 through 4

The two sets of seals were used for 12 starts for 29.25 minutes of ambient GN_2 checkout testing at 3351 rad/sec (3200 rpm) from 17623689 n/m^2 (250 psi) to 22063223 n/m^2 (3200 psi) GN_2 inlet pressure.

The first assembly was tested for 3 starts and 7.5 minutes at 1723689, 3447378, and 6894757 n/m^2 (250, 500, and 1000 psig). The inside diameter of the carbon ring wore most noticeably on the turbine end primary ring and the pump end secondary ring. However, the turbine end primary ring was installed backward causing it to wear excessively. The lift pads on those two rings wore away also. The mating ring sleeve had one worn spot. Maximum seal leakage was .054 kg/sec (.121 lb/sec) at 1654741 n/m^2 (240 psig), .0943 kg/sec (.208 lb/sec) at 3199167 n/m^2 (464 psig) and .1428 kg/sec (.315 lb/sec) at 6687914 n/m^2 (970 psig).

The second build was tested for 3 starts and 6.75 minutes at 6894757, 10342135, and 13789514 n/m^2 (1000, 15000, and 2000 psig). The inside diameter of the carbon ring was noticeably worn only on the pump end secondary seal. Little

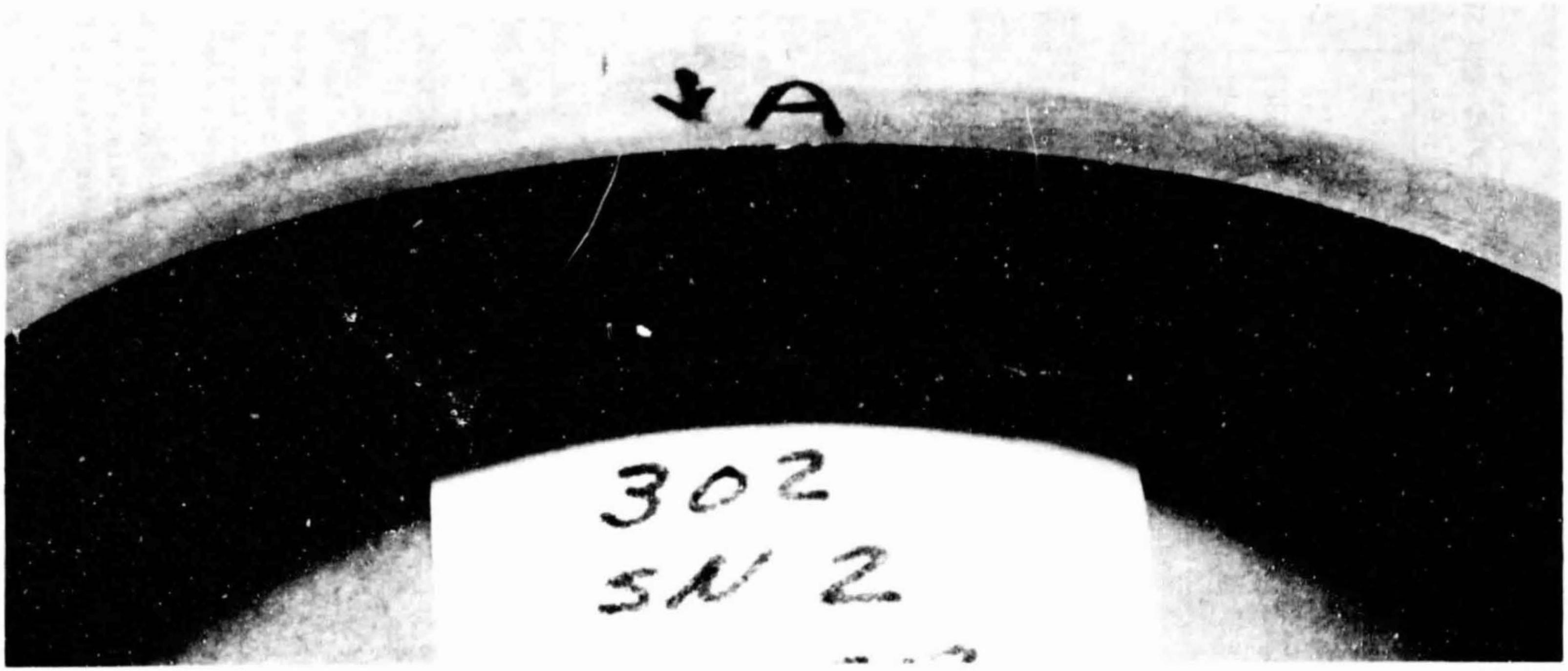


Figure 33. Pump End Primary Seal Ring, P/N 99RS010302, S/N 067602, Build 4, Posttest 12

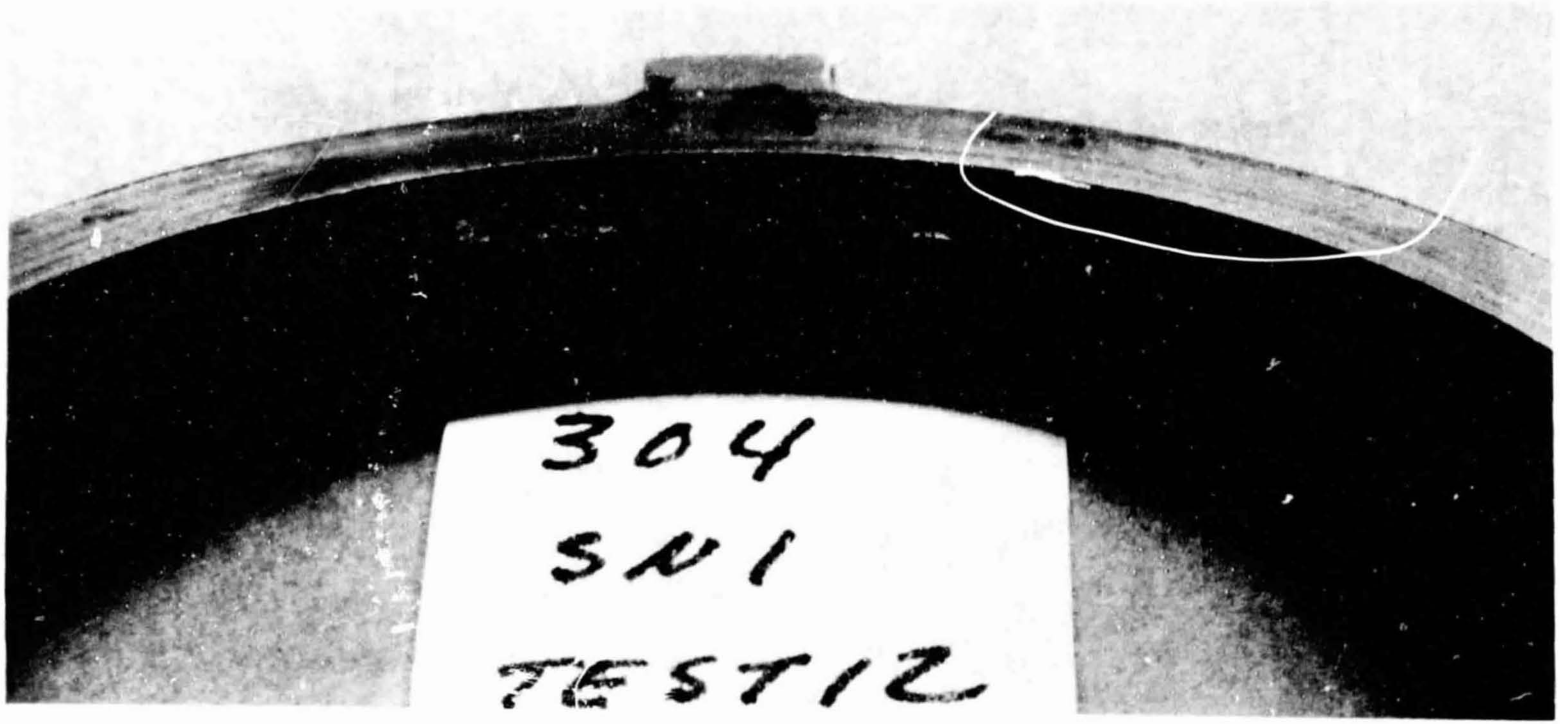


Figure 34. Pump End Secondary Seal Ring, P/N 99RS010304, S/N 067601, Build 4, Posttest 12

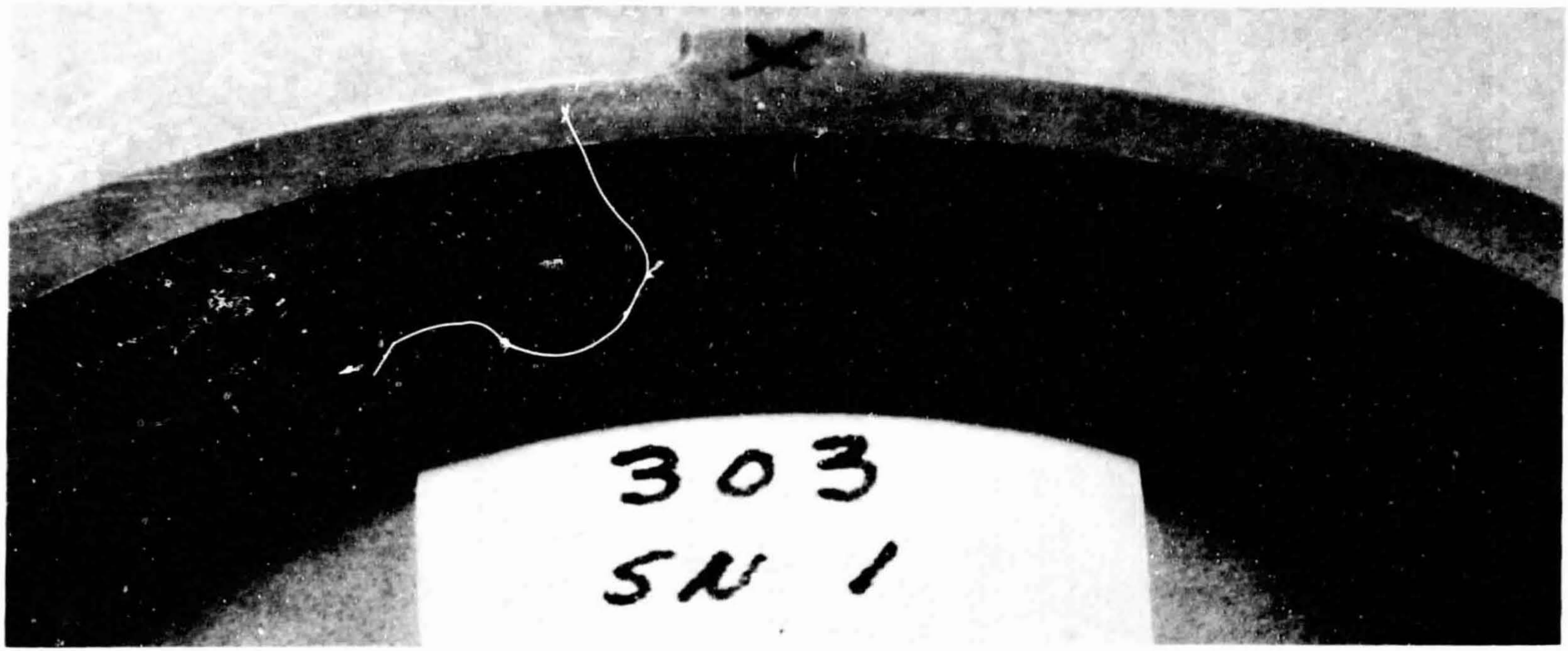


Figure 35. Turbine End Primary Seal Ring, P/N 99RS010303, S/N 067601, Build 4, Posttest 12

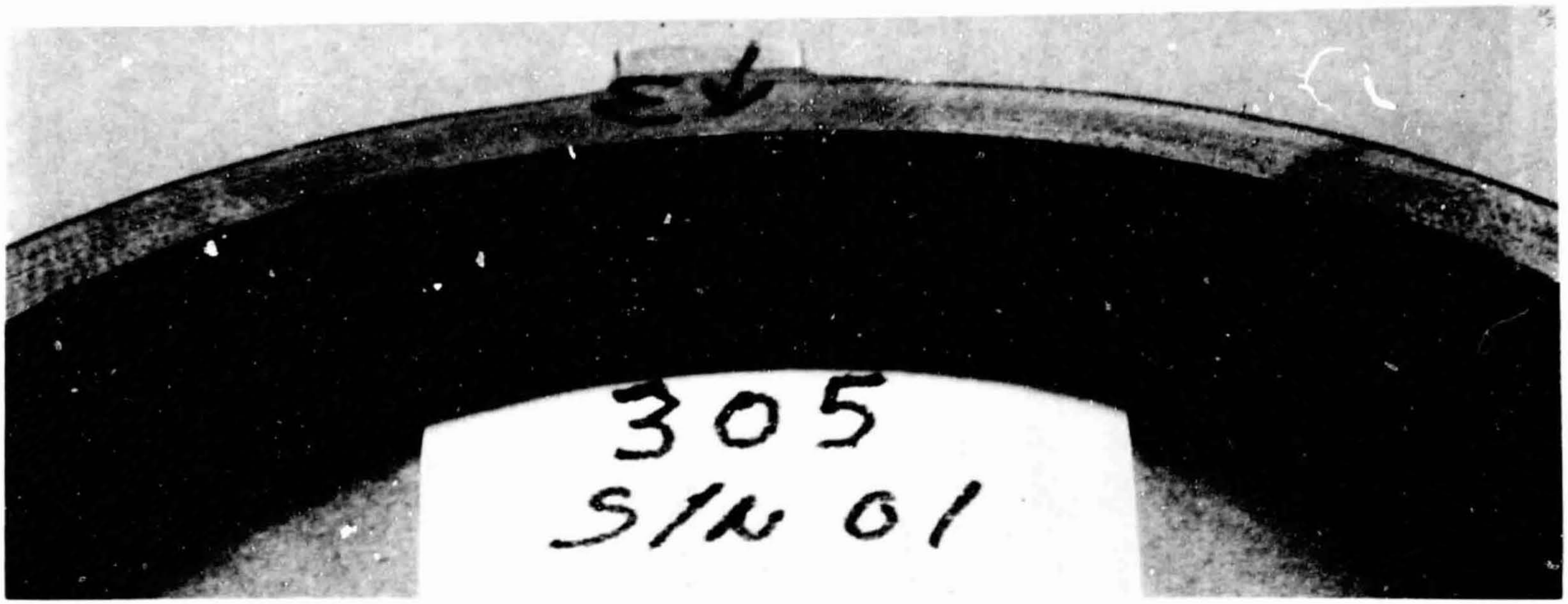
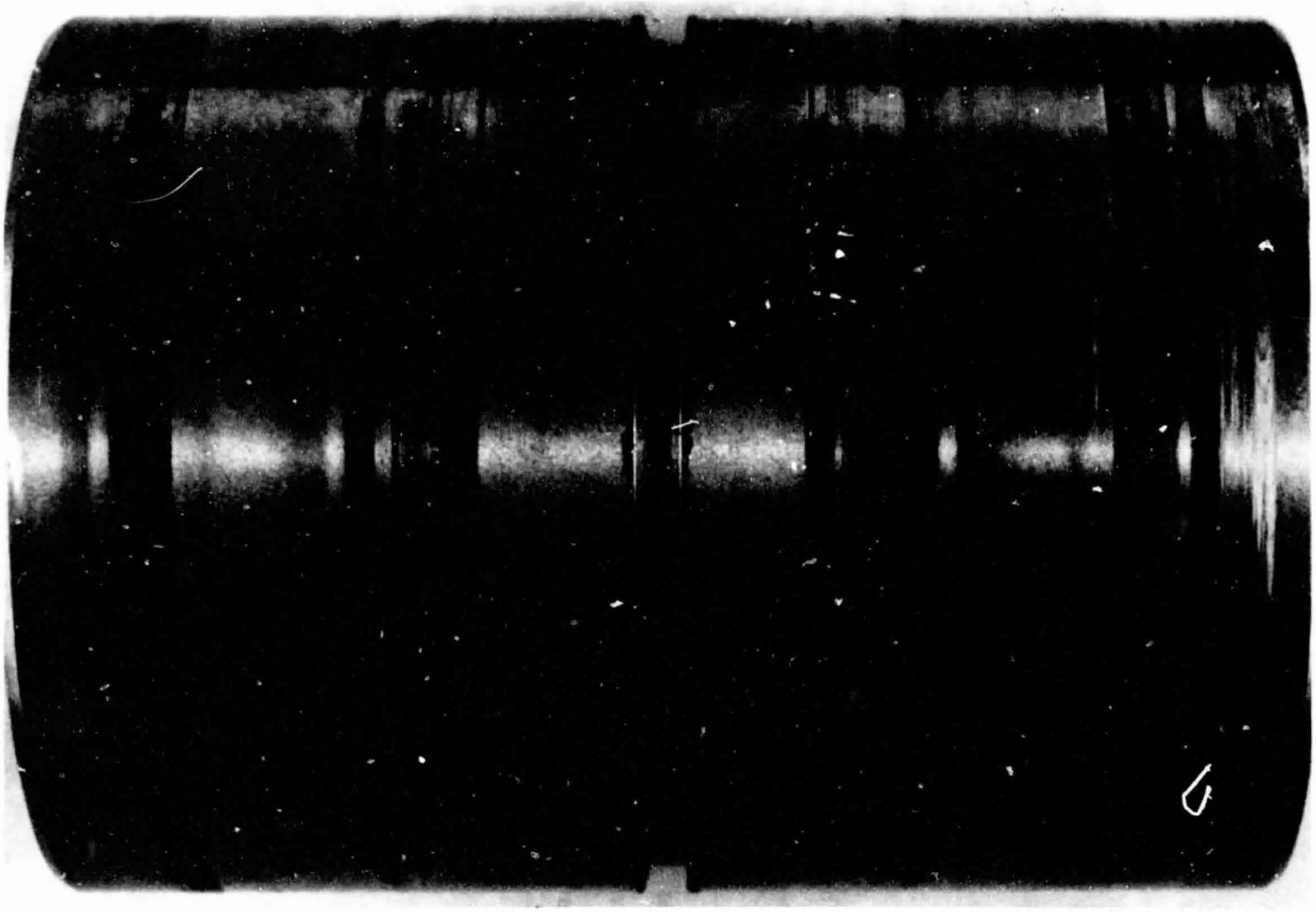


Figure 36. Turbine End Secondary Seal Ring, P/N 99R010305, S/N 067601, Build 4, Posttest 12



PUMP END TURBINE END

Figure 37. Mating Ring Sleeve, P/N RS005092X-00S, S/N 1, Build 4, Posttest 12

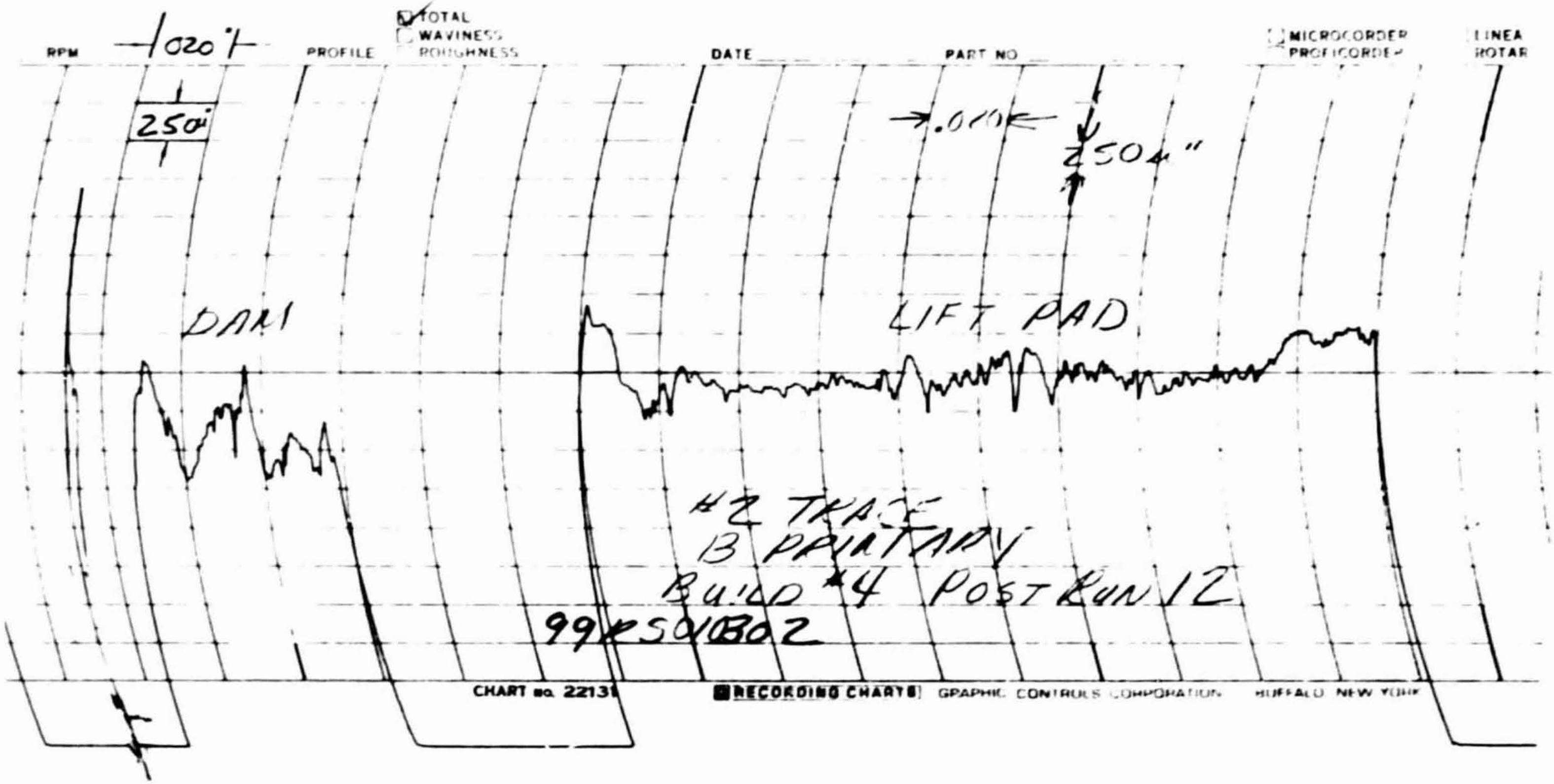


Figure 38. Surface Profile Trace Pump End Primary Seal Lift Pad #2 P/N 99RS010302, S/N 02, Build 4, Posttest 12

TABLE 14. TESTER TURBINE WHEEL RADIAL DISPLACEMENT SUMMARY (1)

	CRITICAL INCREASING				STEADY STATE				CRITICAL DECREASING			
TEST NO.	M	INCH	RAD/SEC	RPM	M	INCH	RAD/SEC	RPM	M	INCH	RAD/SEC	RPM
3	.000170	(.0067)	1185.43	(11,320)	.000045	(.0018)	3392.93	(32,400)	.000330	(.0130)	1282.19	(12,244)
6	.000213	(.0084)	1142.39	(11,320)	.000045	(.0018)	3280.98	(31,331)	.000457	(.0180)	1295.49	(12,371)
7	.001447	(.057)	1142.39	(10,909)	.000058	(.0023)	3306.85	(31,578)	.000828	(.0720)	1231.92	(11.764)
9	.000406	(.016)	1244.178	(11,881)	.000086 .000101	DUAL (.0032) (.0040)	3306.85	(31,578)	.000370	(.0146)	1256.64	(12,000)
12	.000508	(.020)	1196.84	(11,429)	.000033	(.0013)	3351.04	(32,000)	.000203	(.008)	1275.70	(12,182)
17	.000101	(.0040)	1142.39	(11,320)	.000012	(.0005)	3351.04	(32,000)	.000045	(.0018)	1231.92	(11,764)
20	.000058	(.0023)	1256.64	(12,000)	.000012	(.0005)	3351.04	(32,000)	.000060	(.0024)	1396.23	(13,333)
81	.000152	(.0060)	1256.64	(12,000)	.000053	(.0021)	3351.04	(32,000)	.000297	(.0117)	1214.12	(11,594)
91	.000271	(.0107)	1174.33	(11,214)	.000050	(.0020)	3351.04	(32,000)	.000279	(.0110)	1403.56	(13,403)
105	.000254	(.0100)	1196.74	(11,428)	.000050	(.0020)	3351.04	(32,000)	.000297	(.0117)	1351.20	(12,903)
106	.000076	(.0030)	1219.98	(11,650)	.000050	(.0020)	3351.04	(32,000)	.000297	(.0117)	1269.31	(12,121)
107	.000259	(.0102)	1168.88	(11,162)	.000050	(.0020)	3242.96	(30,968)	.000330	(.0103)	1351.20	(12,903)

(1) SHAFT DISPLACEMENT AT THE TEST SEAL IS APPROXIMATELY ONE-HALF OF THE TURBINE WHEEL DISPLACEMENT

additional wear on both the lift pads and the sleeve occurred. Maximum leakage again occurred at the turbine end primary seal measuring .1306 kg/sec (.288 lb/sec) at 6618966 n/m^2 (960 psig), 2140 kg/sec (.472 lb/sec) at 10135293 n/m^2 (1470 psig) and .2948 kg/sec (.650 lb/sec) at 13444776 n/m^2 (1950 psig).

The third build was tested for 3 starts and 7.5 minutes, at pressure of 13789514, 17236893, and 20684271 n/m^2 (2000, 2500, and 3000 psig). Carbon ring diametral wear increased slightly on the seals with the most being .00002286 m (.0009 in.) on the pump end secondary seal. All lift pads were worn away; and .00000127 to .00000889 m (.00005 to .00035 in.) wear occurred on the mating ring sleeve. Maximum seal leakage again occurred at the turbine end primary seal measuring .3048 kg/sec (.672 lb/sec) at 13651619 n/m^2 (1980 psig), 3941 kg/sec (.869 lb/sec) at 17236893 n/m^2 (2500 psig) and .4799 kg/sec (1.058 lb/sec) at 20684271 n/m^2 (3000 psig).

The fourth build was tested for 3 starts and 7.5 minutes at pressures of 18615844, 20684271, and 22063273 n/m^2 (2700, 3000, and 3200 psi). Carbon ring diametral wear was negligible on all rings. The lift pads appeared to be completely worn away on all pads. The mating sleeve wear was .00001397 m (.00055 in.). Maximum leakage again occurred at the turbine end primary seal, measuring .4472 kg/sec (.986 lb/sec) at 18615844 n/m^2 (2700 psig), .5279 kg/sec (1.164 lb/sec) at 20684271 n/m^2 (3000 psig), and .5579 kg/sec (1.230 lb/sec) at 22063223 n/m^2 (3200 psig).

RAYLEIGH STEP SEAL HOT GASEOUS NITROGEN TESTING

Build 5 Assembly Pretest 013

The tester was reassembled with new seal rings and shaft sleeve. The seal hardware summary is given in Table 7 . The same seal housings were used. The seal ring diametral clearances at assembly are given in Table 8 . The seal ring lift pad depths at assembly are given in Table 8 . Shaft sleeve to housing diametral clearances was .0008306 m (.0327 in.) at the turbine end and .0008103 m (.0319 in.) at the pump end.

Tests 013 through 016

Test Points 1 through 4 (Tests 013 through 016) of the Schedule II Hot Gaseous Nitrogen test series were performed using gaseous nitrogen at a temperature of 533K (500 F) and pressures of 3447378, 6894757, 10342135, and 13789514 n/m^2 (500, 1000, 1500, and 2000 psig). The seals were pressurized to 344737 n/m^2 (50 psig) and increased to the test level after start of rotation. The pressure was vented to 344737 n/m^2 (50 psig) prior to stopping rotation. The tester was run at a steady speed of approximately 3351 rad/sec (32000 rpm) for 2.5 minutes. The total time at steady speed was 10 minutes. The tester shaft peak-to-peak radial displacement measured at the turbine wheel is given in Table 14. The shaft displacement at the seal is approximately one-half of the wheel displacement. Seal leakage data for these tests are given in Table 12.

Build 5 Disassembly Posttest 016

Inspection revealed that the seal rings had rubbed the mating ring sleeve and worn the carbon inside diameter. The seal ring diametral wear is shown in Table 8 .

Visual inspection revealed that the lift pads were worn away on the turbine end secondary seal ring. The wear on the other lift pads was negligible. The lift pad wear data are shown in Table 8.

The mating ring sleeve had a rub pattern with a deposit of carbon in the area of the seal rings. The tungsten carbide surface was in good condition with no measureable wear, except for one area at the turbine end seal secondary ring. The surface was worn .000001778 m (.00007 in.) at the sealing dam location.

Inspection revealed the tester shaft had rubbed the seal housing. The original measurements indicated that there was a .0004064 m (.016 in.) radial clearance between the sleeve and the housing. The test data indicate a maximum radial displacement at the seal of .0002286 m (.009 in.) on Test 013, and .0002794 m (.011 in.) on Test 014. The data indicate that the displacement transducer rubbed the turbine wheel on Test 013.

At that point, it became necessary to revise the assembly procedures and refine the balancing procedures to eliminate the excessive radial shaft displacement.

Build 6 Assembly Pretest 17

Prior to assembly, the sleeve that locates the turbine wheel was inspected, assembled in the tester, and measured for axial and radial runout. The following values were measured: axial runout - .00000508 m (.0002 in.); radial runout - .00000508 m (.0002 in.). The results indicate that the runouts were satisfactory.

The tester assembly procedures were revised to increase the axial preload on the shaft stack-up by prolycoating the threads and head of the bolt that loads the turbine wheel against the shaft sleeve. Also, the bolt torque was increased from 169 to 203 m-n (125 to 150 ft-lb). The higher axial loading increases the shaft stiffness to reduce radial displacement. The tester was rebalanced without the test seals using the three-point method at 31.4 and 733 rad/sec (300 and 7000 rpm). The turbine wheel was removed and reinstalled to check for balance repeatability at 31.4 and 733 rad/sec (300 and 7000 rpm) the radial diaplacement measured at the wheel indicated good repeatability (Table 15).

The wheel was removed and reinstalled without the test seals to measure the wheel radial displacement during the critical speed transient and at a steady speed of 3141 rad/sec (30000 rpm). A balance check at 733 rad/sec (7000 rpm) indicated excellent repeatablility (Table 15). The tester was accelerated through the critical speed, run at 3141 rad/sec (30,000 rpm) for 30 seconds and coasted through the critical speed while stopping. The wheel was then removed and reinstalled to check for repeatability during the critical at steady speed. The wheel radial displacement repeated exactly. The values were .0001016 m (.0040 in.) at the critical speed and .00003556 m (.0014 in.) at 3141 rad/sec (30,000 rpm)

TABLE 15. BALANCE TEST RESULTS

BALANCE RUN	SPEED RAD/SEC (RPM)	WHEEL RADIAL P-P DISPLACEMENT m (IN)	REMARKS
1	31.4 (300)	0.00002031 (0.0008)	PRIOR TO BALANCE (NO SEALS)
2	733 (7,000)	0.000127 (0.0050)	PRIOR TO BALANCE (NO SEALS)
3	314 (3,000)	0.00002031 (0.0008)	BALANCE TEST (NO SEALS)
4	733 (7,000)	0.00005581 (0.0022)	BALANCE TEST (NO SEALS)
			REMOVED AND REINSTALLED WHEEL
5	31.4 (300)	0.00002031 (0.0008)	REPEAT OF BALANCE TEST (NO SEALS)
6	733 (7,000)	0.0000254 (0.0010)	REPEAT OF BALANCE TEST (NO SEALS)
			REMOVED AND REINSTALLED WHEEL
7	733 (7,000)	0.00002031 (0.0008)	REPEAT OF BALANCE TEST (NO SEALS)
8	3193 (30,500)	0.00003551 (0.0014)	STEADY STATE
8	1196 (11,428)	0.0001016 (0.0040)	CRITICAL SPEED COASTING DOWN
			REMOVED AND REINSTALLED WHEEL
9	3141 (30,000	0.00003301 (0.0013)	REPEAT OF STEADY STATE (NO SEALS)
9	1251 (11,952)	0.0001014 (0.0040)	REPEAT OF CRITICAL SPEED (NO SEALS)
			REMOVED AND INSTALLED WHEEL INSTALLED TEST SEALS
10	31.4 (300)	0.00002031 (0.0008)	REPEAT OF BALANCE TEST WITH SEALS
11	733 (7,000)	0.00002031 (0.0008)	REPEAT OF BALANCE TEST WITH SEALS

with indication of subsynchronous whirl. The results are given in Table 15 and shown in Fig. 39 and 40.

The wheel was removed again to install the test seals. The same seal hardware from Build 5 was reinstalled. A balance check at 31.4 and 733 rad/sec (300 and 7000 rpm) indicated excellent repeatability (Table 15). A total of 11 balancing tests were performed: 9 without the seals and 2 with seals installed.

Tests 017 through 020

Test Points 5 through 8 (Tests 017 through 020) of the Schedule II Hot Gaseous Nitrogen test series were performed using gaseous nitrogen at temperatures of 422 to 533K (300 to 500 F) and pressures of 17236893, 20684271, 22407960, and 26027708 n/m^2 (2500, 3000, 3500, and 3775 psig). The seals were pressurized to 344737 n/m^2 (50 psig) and increased to the test level after start of rotation. The pressure was vented to 344737 n/m^2 (50 psig) prior to stopping rotation.

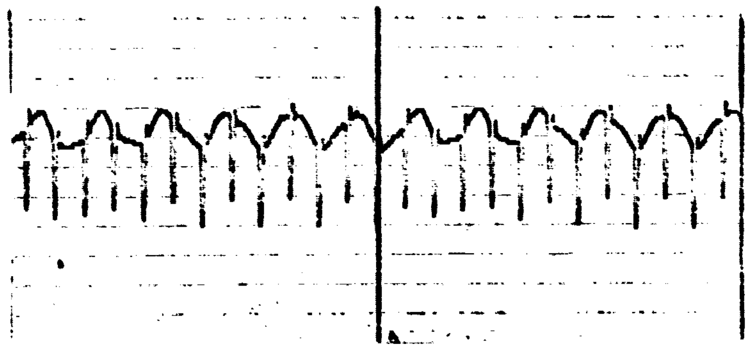
The tester was accelerated to test speed, 3351 rad/sec (32000 rpm) and held steady for 2.5 minutes. The total time at steady speed was 10 minutes. The tester shaft peak-to-peak radial displacement measured at the turbine wheel throughout the test is shown in Table 14. The shaft displacement at the seal is approximately one-half of the wheel displacement. Seal leakage data are shown in Table 12. The test plan was revised to delete the second set of Schedule II seal testing. Therefore, this series of tests completed Schedule II testing.

Build 6 Disassembly Posttest 020

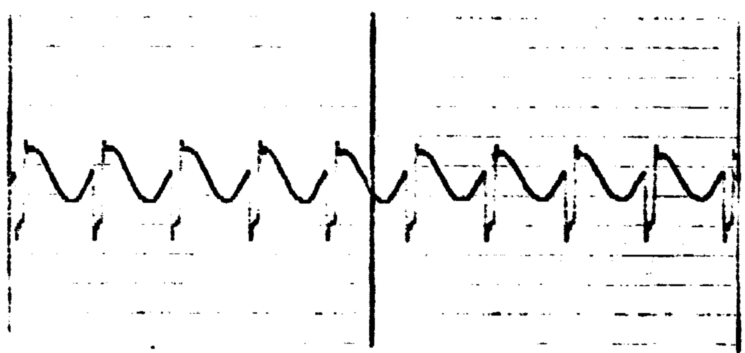
Measurement of the carbon seal ring inside diameters revealed no significant additional wear since Test 016. The seal ring diametral wear is shown in Table 8. The lift pads had previously worn away on the turbine end seal secondary ring. The wear on the other lift pads was negligible The lift pad wear data are shown in Table 8. The upstream edge of the turbine end seal primary ring dam was eroded in the axial direction around the circumference from .0007366 to .001016 m (.029 to .040 in.). The erosion wear was apparently caused by the high-velocity gas leakage at the sealing dam. There was no significant erosion on the other seal rings. The axial sealing dam nose height on the side surface at the stationary housing was worn slightly on both primary seal rings. The measured wear is shown below:

SEAL	TURBINE END		PUMP END	
	PRIMARY	SECONDARY	PRIMARY	SECONDARY
WEAR M (IN.)	.00001524(.0006)	0	.00001778(.0007)	0

The mating ring sleeve had a rub pattern with a deposit of carbon in the area of the seal rings. The tungsten carbide surface was in good condition with no measureable wear, since Test 016. Inspection revealed that there was no additional rubbing between the mating ring sleeve and the seal housing. The seal hardware and surface profile traces are shown in Fig. 41 through 48.

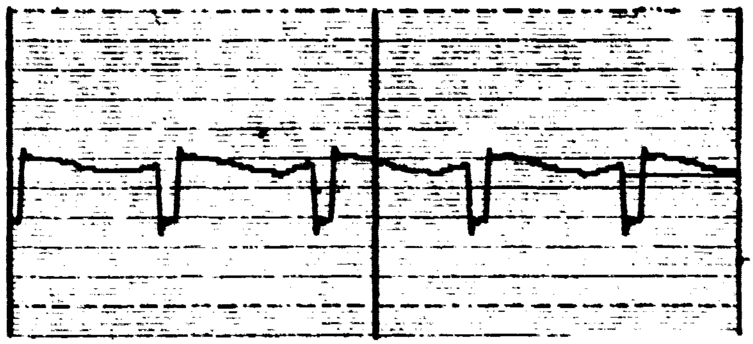


(a) Steady at 3193 rad/sec (30,500 rpm)
(Subsynchronous Whirl)



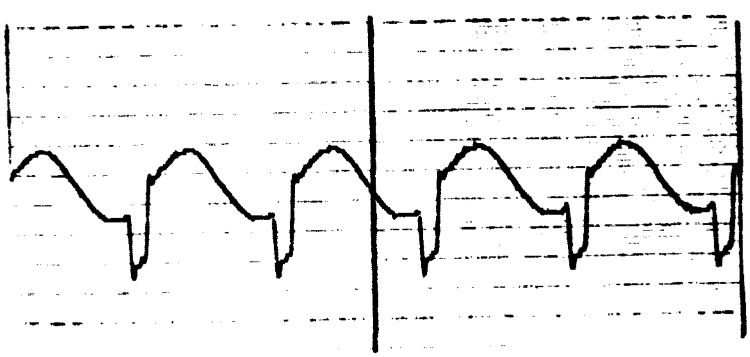
(b) Critical Coasting Down at 1196 rad/sec
(11,428 rpm)

Figure 39. Turbine Wheel Radial Displacement Traces From High Frequency Data on Balance Test 8 (Calibration Notch = 0.0001016 m (0.004 inch)



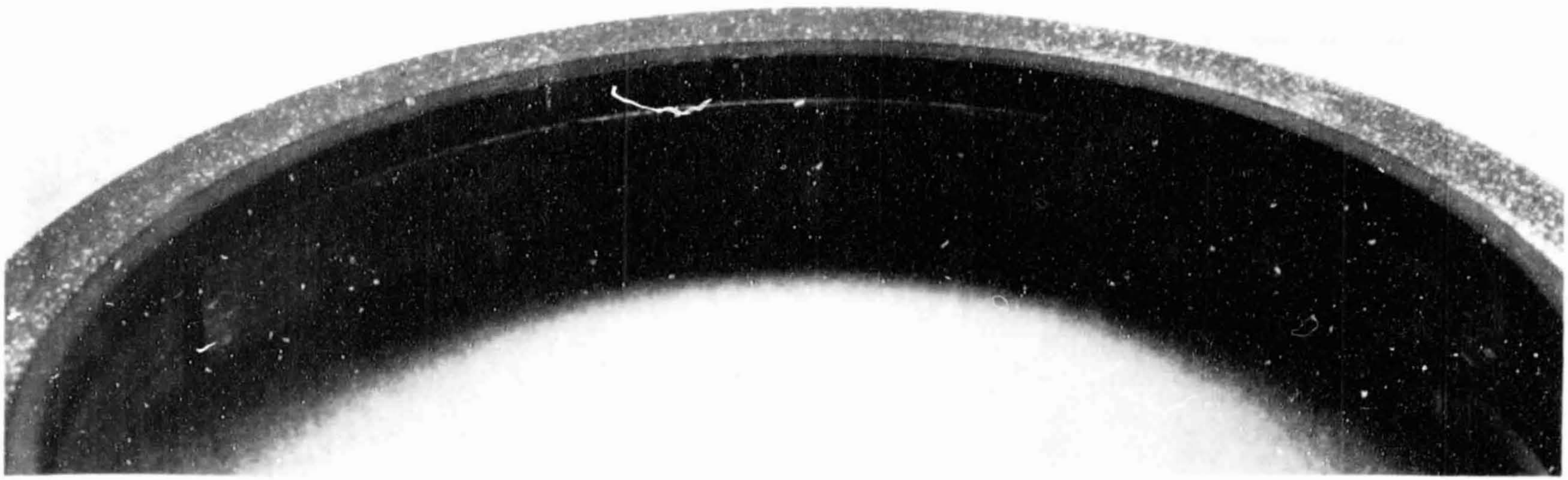
(a) Critical Accelerating at 1185 rad/sec (11,320 rpm)

(b) Steady at 3141 rad/sec (30,000 rpm) (Subsynchronous Whirl)



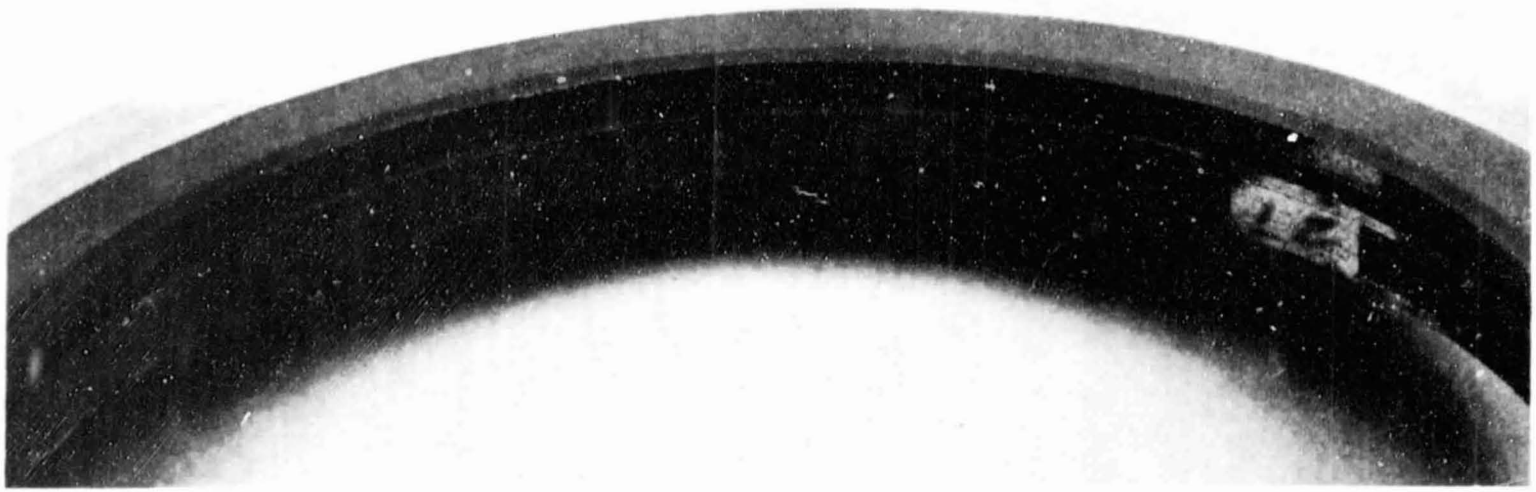
(c) Critical Coasting Down at 1185 rad/sec (11,320 rpm)

Figure 40. Turbine Wheel Radial Displacement Traces From High Frequency Data on Balance Test 9 (Calibration Notch = 0.0001016 m (0.004 inch)



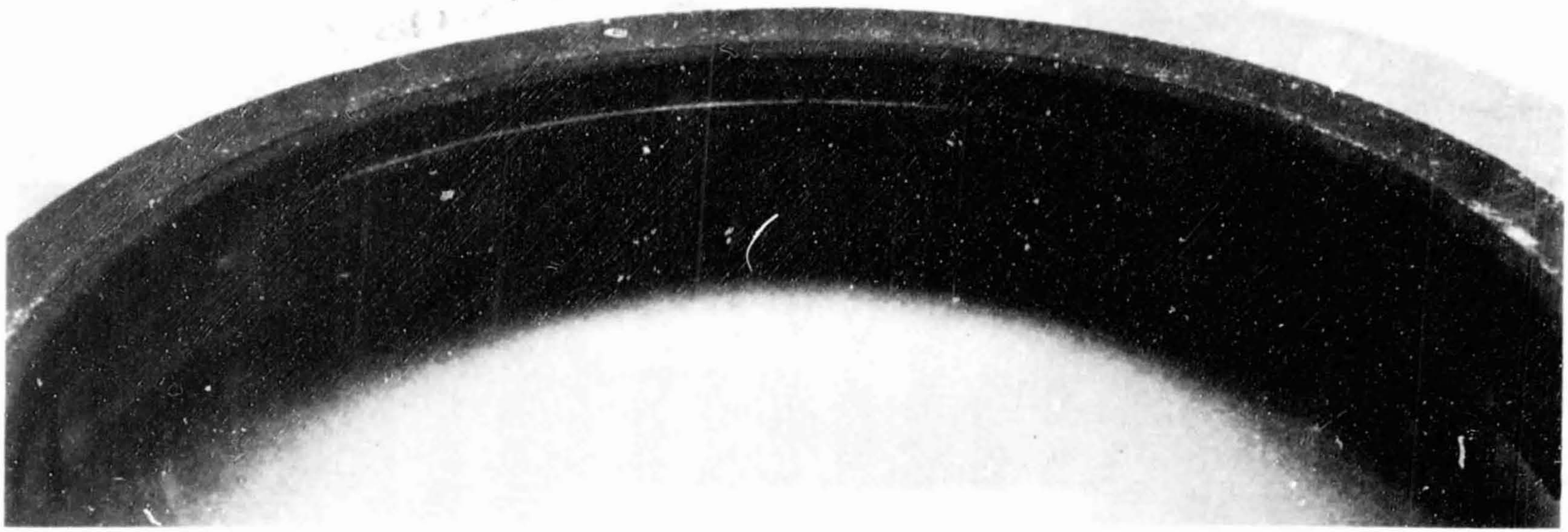
1XY55-2/10/78-C1C

Figure 41. Pump End Primary Seal Ring, P/N 99RS010302, S/N 04, Build 6, Posttest 20



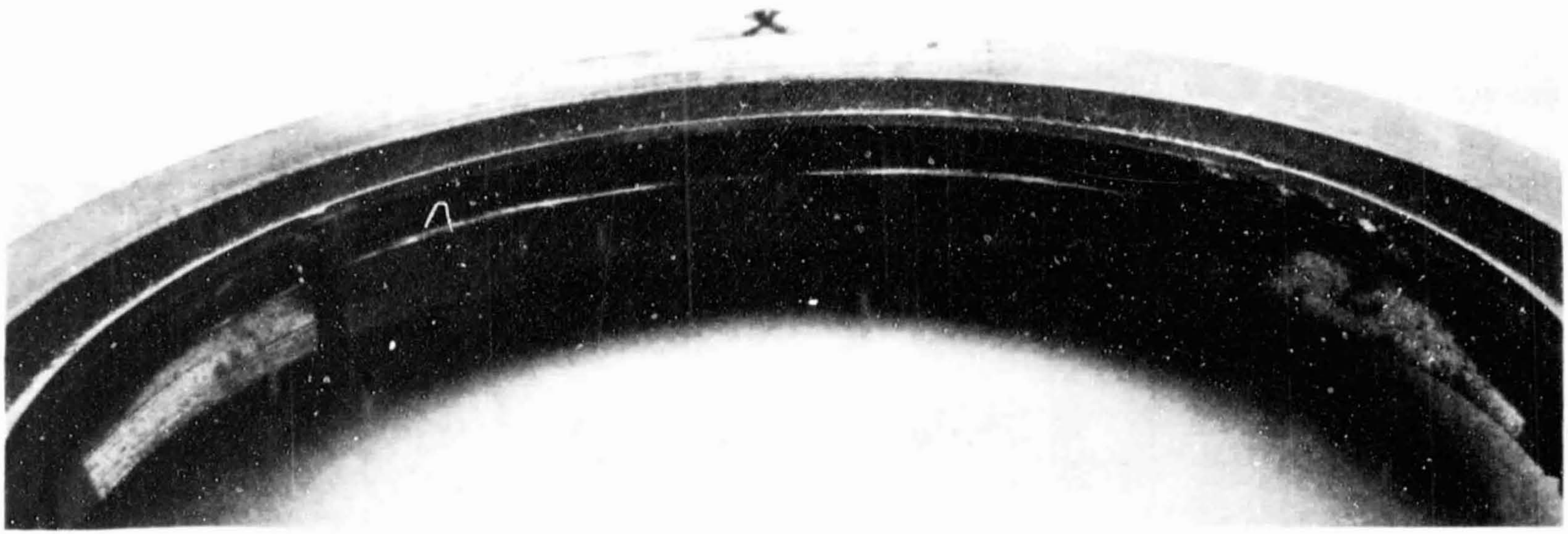
1XY55-2/10/78-C1A

Figure 42. Pump End Secondary Seal Ring, P/N 99RS010304,
S/N 04, Build 6, Posttest 20



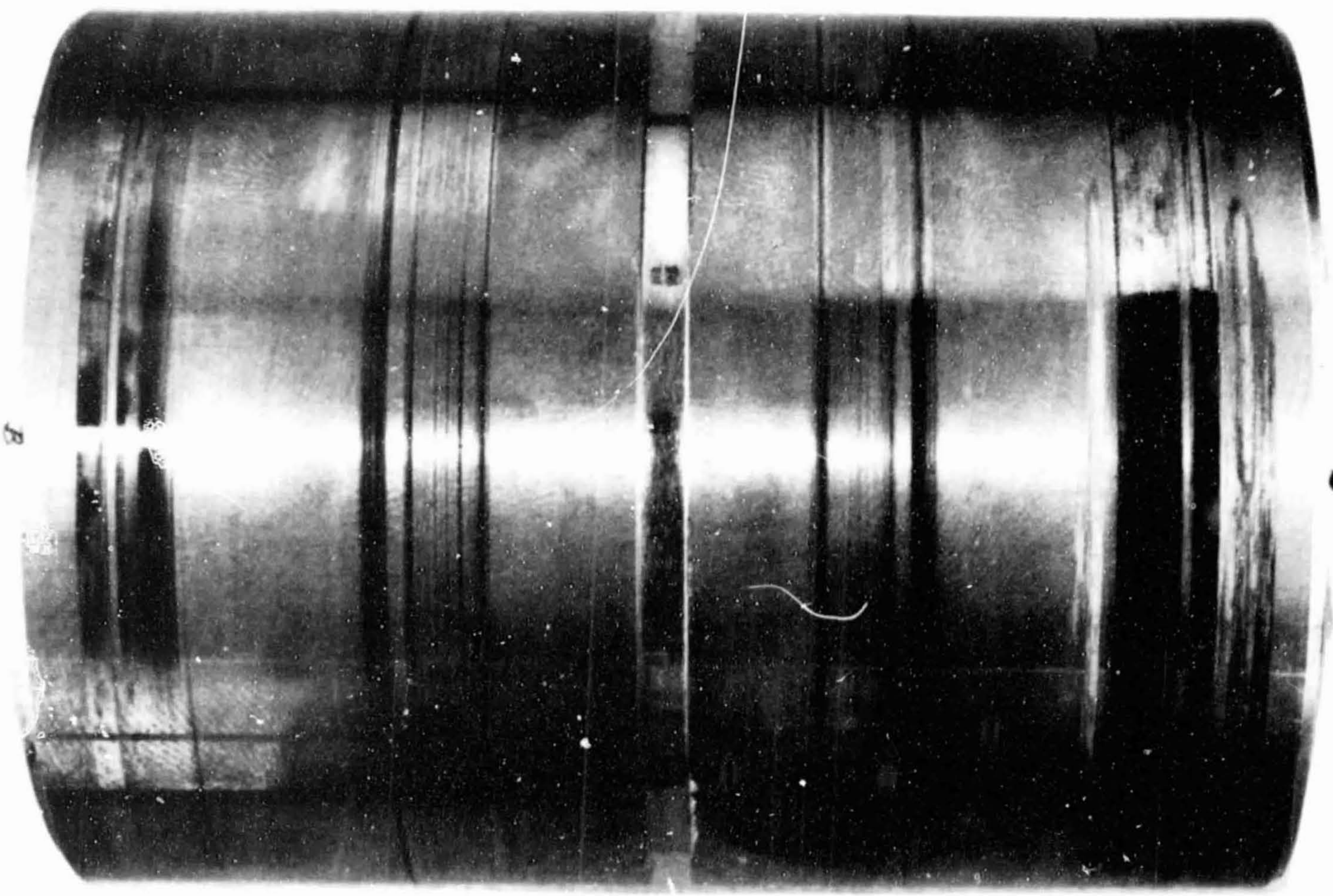
1XY55-2/10/78-C1D

Figure 43. Turbine End Primary Seal Ring, P/N 99RS010303, S/N 06, Build 6, Posttest 20



1XY55-2/10/78-C1E

Figure 44. Turbine End Secondary Seal Ring, P/N 99RS010305, S/N 05, Build 6, Posttest 20



PUMP END TURBINE END

LXY55-2/10/78-C1B

Figure 45. Mating Ring Sleeve, P/N RS005092X-005, S/N 2, Build 6, Posttest 20

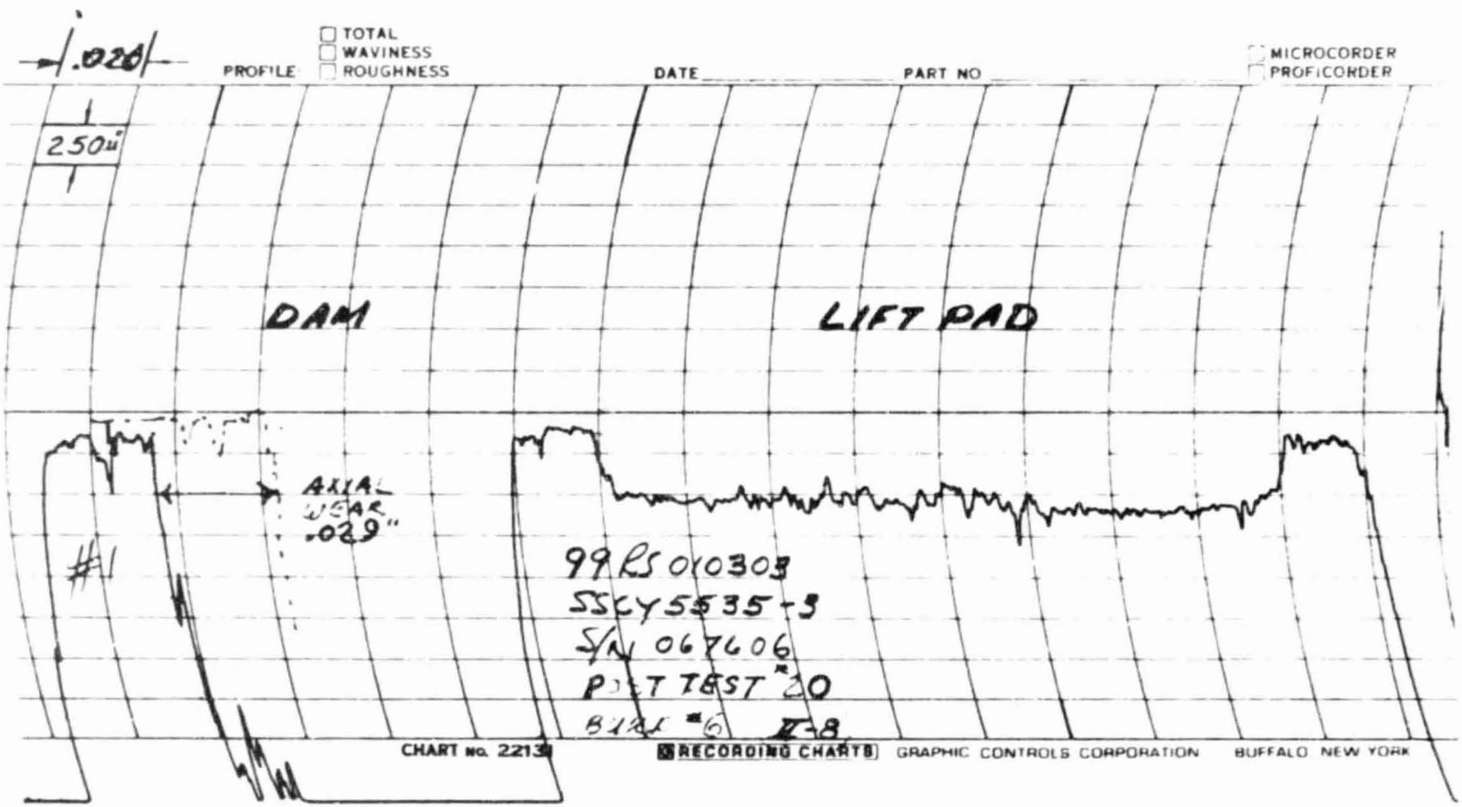


Figure 46. Surface Profile Trace Turbine End Primary Seal Lift Pad 1, P/N 99RS010303, S/N 06, Build 6, Posttest 20

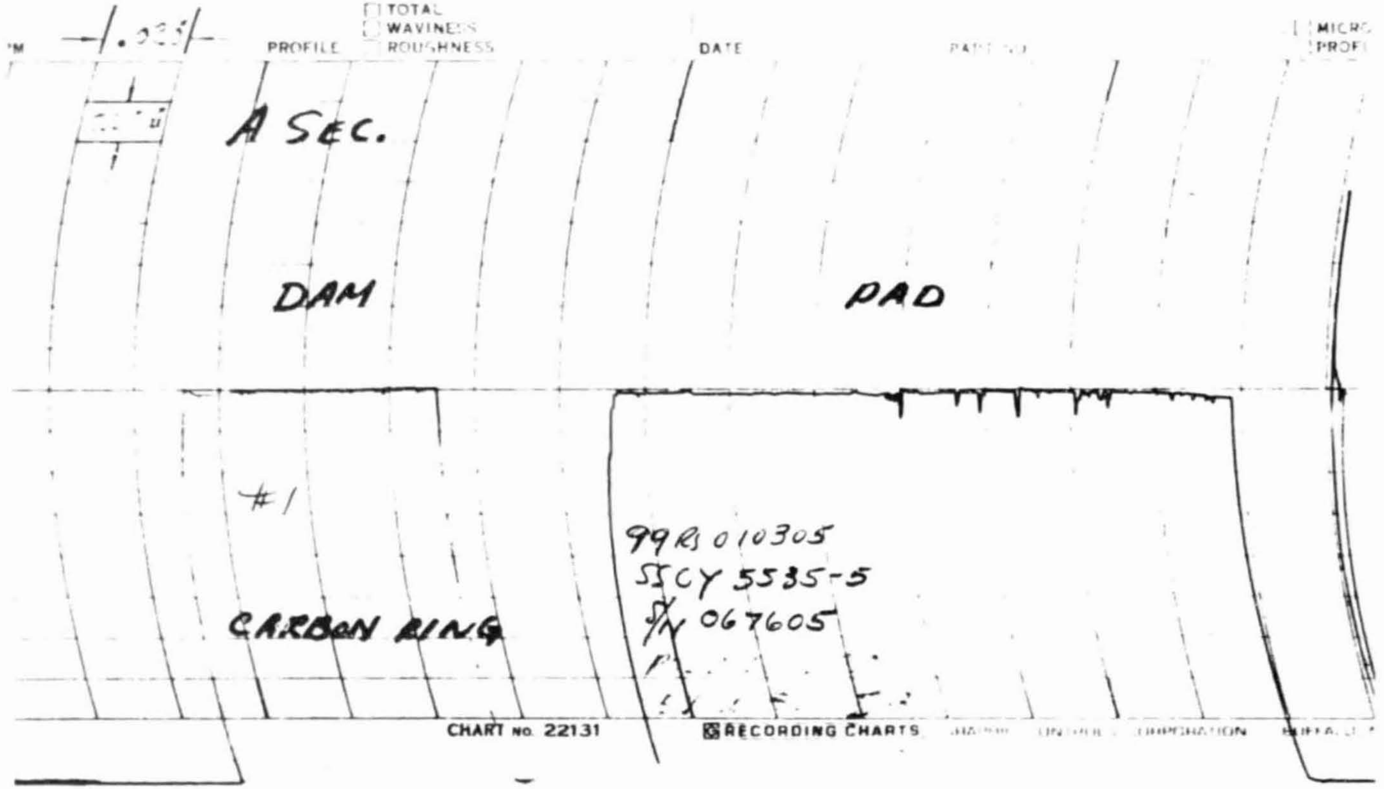


Figure 47. Surface Profile Trace Turbine End Secondary Seal
P/N 99RS010305, S/N 05, Build 6, Posttest 20

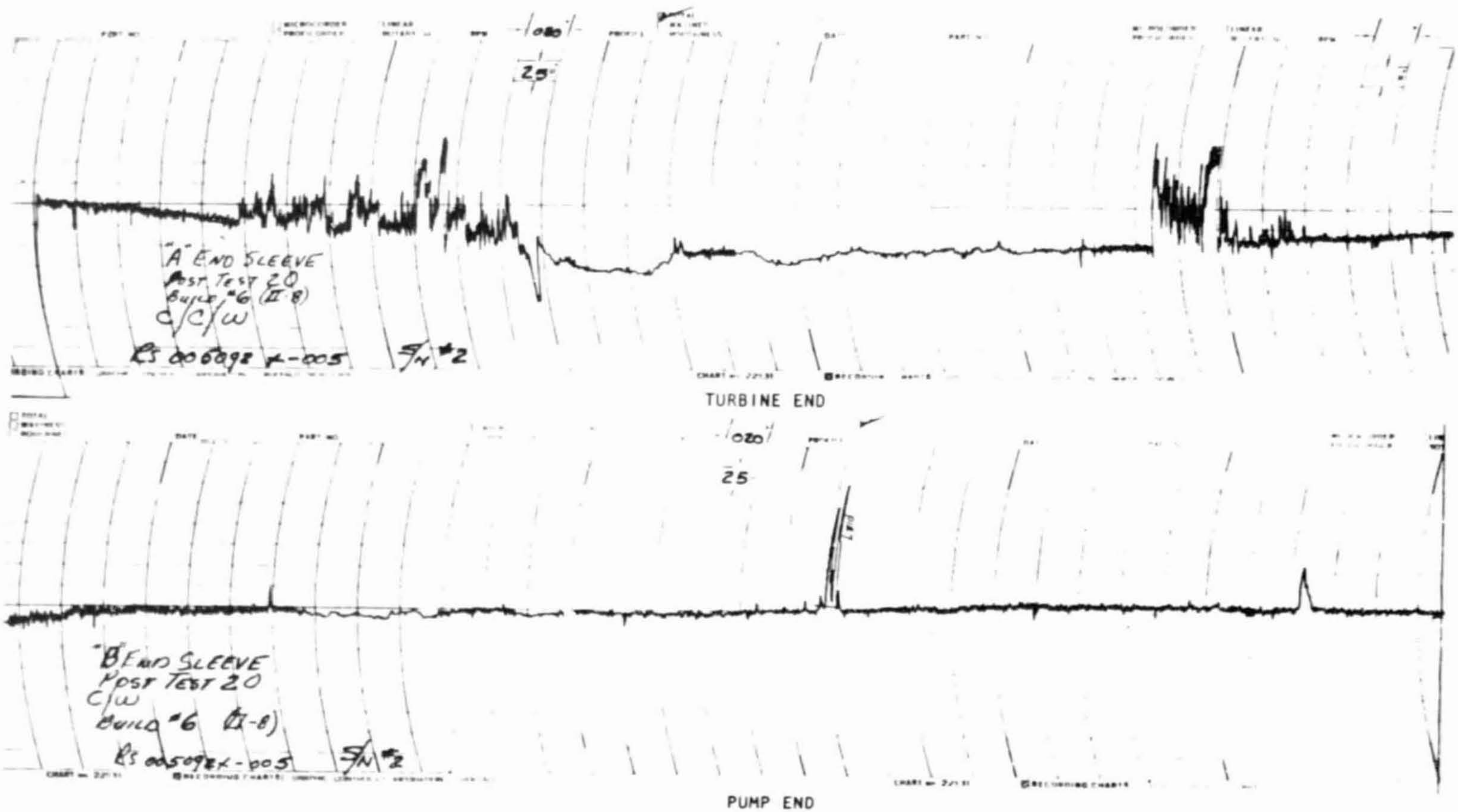


Figure 48. Surface Profile Trace of Tester Mating Ring Sleeve, P/N RS005092X-005, S/N 2, Build 6, Posttest 20

Discussion - Build 5 and 6

A total of 8 tests for 20 minutes on 2 tester builds (5 and 6) was performed. The tests were run with gaseous nitrogen at temperatures from 422 to 533K (300 to 500 F) and pressures in increments of 3447378 n/m^2 (500 psi) beginning at 3447378 n/m^2 (500 psi) the last being run at 26027708 n/m^2 (3775 psi). The tester was accelerated through the critical speed (1256 rad/sec, 12000 rpm) and run at a steady speed of approximately 3351 rad/sec (32000 rpm) for 2.5 minutes each test. Seal performance appeared to be satisfactory. A summary of seal leakage is given in Table 12.

Postbuild 5 inspection showed excessive wear on the turbine end secondary seal ring lift pad height dimension. Some wear was also noticed on the seal ring internal bore on all four seal rings, as well as on the mating ring sleeve. Inspection also revealed the tester shaft sleeve had rubbed the seal housing. The data indicate excessive shaft displacement during rotation. The wear data summary are given in Table 8 .

As a result, the balancing procedures were refined and the tester rebalanced. A total of 11 balancing tests were performed: 9 tests without the seals and 2 with seals installed. Test results indicated that tester shaft radial diplacement had been reduced to an acceptable level. Build 6 testing was then performed.

Post Build 6 inspection revealed no significant additional wear since post Build 5, on both the carbon bore and the lift pad height dimensions. However, the turbine end primary seal ring dam was noticed to be worn in the axial direction around the circumference, apparently caused by high-velocity leakage. The axial sealing dam nose height on the side surface at the stationary housing was worn slightly on both primary seal rings. There was no additional rubbing between the mating ring sleeve and the seal housing. A summary of Build 6 wear data are given in Table 8 .

RAYLEIGH STEP SEAL ACCELERATION TESTING

Build 7 Assembly Pretest 021

The tester was reassembled with new seal rings and shaft sleeve for the Schedule III testing. The same seal housing was used. A seal hardware summary is shown in Table 7 . The seal ring diametral clearances at assembly is shown in Table 8 . The seal lift pad depths at assembly is shown in Table 8 . The shaft sleeve to housing diametral clearances was .0008382 m (.0330 in.) at the turbine end and .0008255 m (.0325 in.) at the pump end. The axial nose height was measured as:

	TURBINE END		PUMP END	
	PRIMARY	SECONDARY	PRIMARY	SECONDARY
NOSE HEIGHT M (IN.)	.0005588(.0220)	.0005384(.0212)	.00056876(.0224)	.0005588(.0220)

Tests 021 Through 029

Test points 1 through 9 (Tests 021 through 029 of the Rayleigh Step Seal Acceleration Test series) were performed using gaseous nitrogen at temperatures of 394 to 533 K (250 to 500 F) and pressures of 23786912 to 25682970 n/m^2 (3450 to 3725 psig). The seals were pressurized to 344737 n/m^2 (50 psig) and increased to the test level concurrent with the speed acceleration to simulate the turbopump start transient. The pressure was vented to 344737 n/m^2 (50 psig) prior to stopping rotation. Total test time at a steady speed of 3351 rad/sec (32,000 rpm) was 29.15 minutes. The tester shaft peak-to-peak radial displacement measured at the turbine wheel throughout the test, is shown in Table 14. The shaft displacement at the seal is approximately one-half of the wheel displacement. The testing was terminated to inspect the seals due to higher than expected seal leakage and drain cavity pressures. The seal leakage varied from .5896 to .8164 kg/sec (1.3 to 1.8 lb/sec) on the primary seals and from .1315 to .0362 kg/sec (0.29 to 0.08 lb/sec) on the secondary seals. The hot-gas temperature typically decreased from approximately 533 K (500 F) at start to about 366 K (200 F) at cut-off. The heat exchanger used to bring the GN_2 up to temperature is not sufficient to maintain the temperature at the high flowrate. A summary of the test data is shown in Table 12 .

Build 7 Disassembly Posttest 029

Inspection revealed that the carbon seal rings had rubbed the mating ring sleeve and worn the carbon inside diameter. The seal ring diametral wear varied from .00001524 to .00005842 m (.0006 to .0023 in.). The wear was tapered across the inside diameter with no more wear on the dam side. A summary of the seal ring wear data is shown in Table 8.

The lift pads were worn away on the turbine end secondary seal ring. The wear on the other lift pads varied from zero to .00001524 m (.0006 in.). A summary of the lift pad wear data is shown in Table 8 .

Visual inspection revealed that the dam area of the turbine end primary seal ring was eroded away axially and chipped on the upstream edge of the carbon ring. The measured amount of axial dam wear on the turbine end primary seal ring is shown below. The axial dam wear on the other seal rings was negligible.

POSITION	1	2	3	4
DAM WEAR m (IN.)	.000408(.020)	Ø	Ø	.000762(.030)

The sealing dam nose on the side surface of the carbon rings was worn as shown below:

SEAL	TURBINE END		PUMP END	
	PRIMARY	SECONDARY	PRIMARY	SECONDARY
NOSE WEAR m (IN.)	.00001016(.0004)	.0002515(.0099)	.00000508(.0002)	.0002642(.0104)

The mating ring sleeve had a rub pattern with a deposit of carbon in the area of the seal rings. The tungsten carbide surface was in good condition with no measurable wear, except for .00000254 m (.0001 in.) at the sealing dam location. Inspection revealed the tester shaft sleeve had not rubbed the seal housing. There was no evidence of high vibration or shaft displacements.

Build 8 Assembly Pretest 030

The tester was reassembled with the same hardware as Build 7. The seal lift pad depths at assembly are given in Table 8 . The axial nose height at assembly is shown below:

SEAL	TURBINE END		PUMP END	
	PRIMARY	SECONDARY	PRIMARY	SECONDARY
NOSE HEIGHT m (IN.)	.0005486(.0216)	.00031242(.0123)	.0005683(.0222)	.000 2946 TO .00054356 (.0116 TO .0214)

Tests 030 Through 080

Tests 30 through 80 were performed using gaseous nitrogen at temperatures of 394 to 533 K (250 to 500 F) and pressures of 23786912 to 25682970 n/m^2 (3450 to 3725 psig). The seals were pressurized to 344737 n/m^2 (50 psig) and increased to the test level concurrent with the speed acceleration to simulate the turbopump start transient. The pressure was vented to 344737 n/m^2 (50 psig) prior to stopping rotation.

A total of 51 tests for 121 minutes at a steady-state speed of 3351 rad/sec (32000 rpm) was performed. A minor modification in the facility was made to reduce the back pressure in the pump end drain cavity.

The tester shaft peak-to-peak radial displacement measured throughout the test is given in Table 14 . The shaft displacement at the seal is approximately one-half of the wheel displacement.

The testing was terminated for a scheduled seal inspection. The seal leakage data are given in Table 12 . The hot gas temperature typically decreased from about 533 K (500 F) at start to 366 K (200 F) at cut-off. The heat exchanger capacity is not sufficient to maintain the temperature at the high flowrate.

Build 8 Disassembly Posttest 080

Inspection revealed that the carbon seal rings had rubbed the mating ring sleeve and worn the carbon inside diameter. The seal ring diametral wear varied from .00000508 to .0000762 m (.0002 to .0030 in.). The wear was tapered from the turbine end secondary seal to the pump end seals with more wear on the turbine end. A summary of seal ring diametral wear is given in Table 8 .

The lift pads were worn away on the turbine end secondary seal ring. Most of the lift pads were badly worn on the turbine end primary seal ring. The wear on the other lift pads varied from 0 to .00000508 M (.0002 in.). A summary of lift pad height wear is given in Table 8.

The dam area of the turbine end primary seal ring was eroded away axially and chipped on the upstream edge. The measured amount of axial dam wear on the turbine end primary seal ring is shown below. The axial dam wear on the other seal rings was negligible.

POSITION	1	2	3	4
DAM WEAR M (IN.)	.000762(.030)	0*	.000889(.035)	.000762(.030)
*SAME AS POST TEST 29				

The sealing dam nose on the side surface of the carbon rings was worn as shown below:

SEAL	TURBINE END		PUMP END	
	PRIMARY	SECONDARY	PRIMARY	SECONDARY
NOSE WEAR M (IN.)	ADDITIONAL .00000508(.0002)	.00000508(.0002)	.00000508(.0002)	0
	TOTAL .00001016(.0004)	.0002667(.0105)	.00001016(.0004)	.000226(.0089)

The mating ring sleeve had a rub pattern with signs of carbon in the area of the seal rings. The tungsten carbide surface was in good condition with no measurable wear, except for .0000005O8M(.00002 in.) at the sealing dam location. Inspection revealed that the test shaft sleeve had not rubbed the seal housing.

There was no evidence of high vibration or shaft displacements.

Build 9 Assembly Pretest 081

The tester was reassembled with the same seal hardware as Build 8. The seal ring lift pad depths at assembly are given in Table 8 . The axial nose height at assembly is shown below:

SEAL	TURBINE END		PUMP END	
	PRIMARY	SECONDARY	PRIMARY	SECONDARY
NOSE HEIGHT, M (IN.)	.0005486(.0216)	.00031242(.0123)	.0005588(.0220)	.0002921 TO .000381 (0115 TO .015)

Tests 081 Through 107

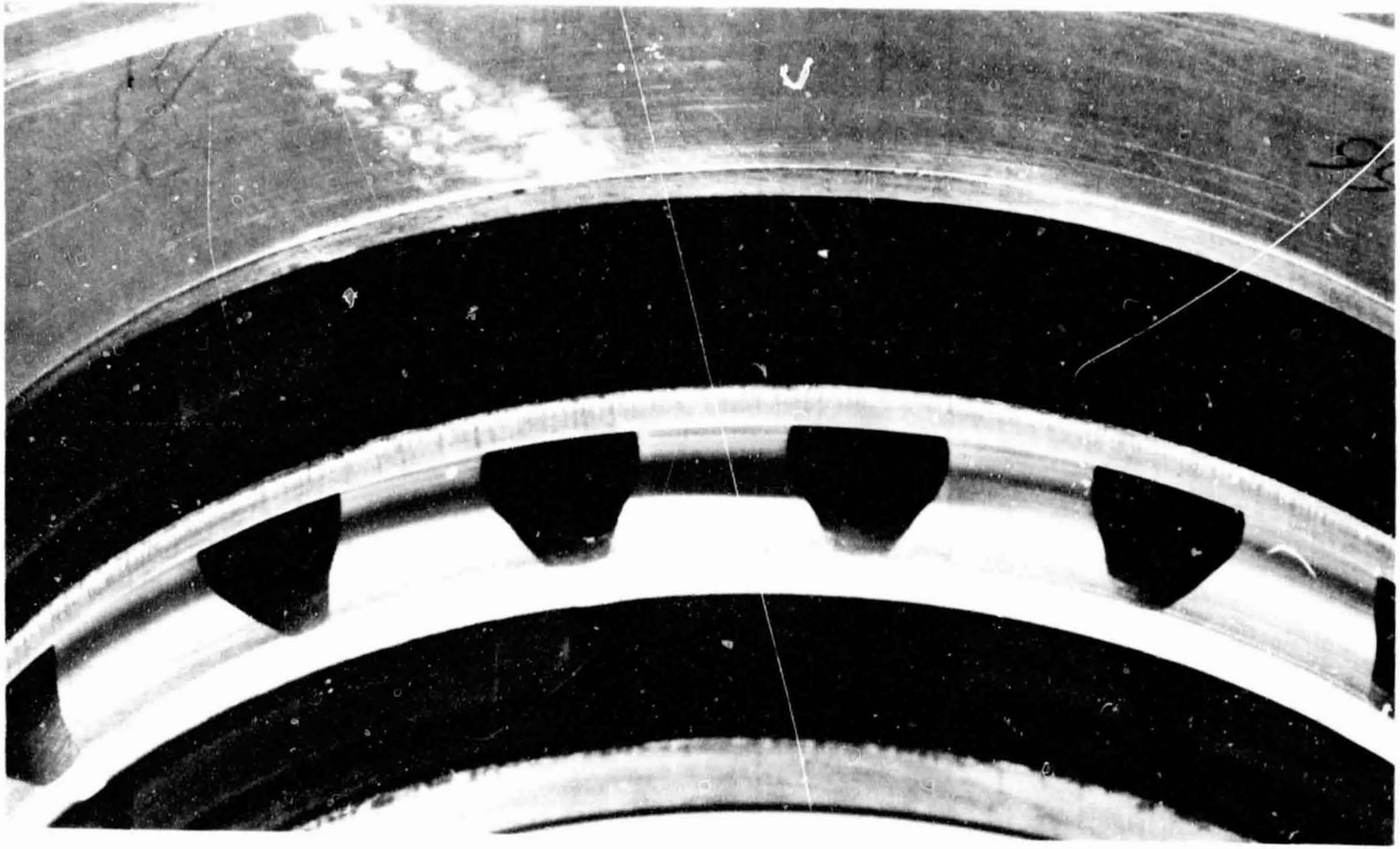
Tests 081 through 107 were performed using gaseous nitrogen at temperatures of 366 to 533 K (250 to 500 F) and pressures of 23786912 to 25682970 n/m^2 (3450 to 3725 psig). The seals were pressurized to 344737 n/m^2 (50 psig) and increased to the test level concurrent with the speed acceleration to simulate the turbopump start transient. The pressure was vented to 344737 n/m^2 (50 psig) prior to stopping rotation.

A total of 27 tests for 71.97 minutes were performed for an accumulated total time of 236.42 minutes on the first set of seals. Test 107 was terminated prematurely due to a sudden large increase in all of the seal drain cavities. The tester was then shut down for disassembly and inspection of the seals.

The tester shaft peak-to-peak radial displacement measured at the turbine wheel throughout the tests are shown in Table 14 . The shaft displacement at the seal is approximately one-half of the wheel displacement. The seal leakage data are given in Table 12 . The hot gas temperature typically decreased from about 533 K (500 F) at start to 366 K (200 F) at cut-off.

Build 9 Disassembly Posttest 107

Inspection revealed that the turbine end primary ring sealing dam had fragmented and broken away completely around the circumference. The pump end seal rings appeared to be in satisfactory condition, except for erosion and wear. The seal assemblies prior to disassembly are shown in Fig.48 through 51 . The seal hardware condition is shown in Fig. 52 through 62.

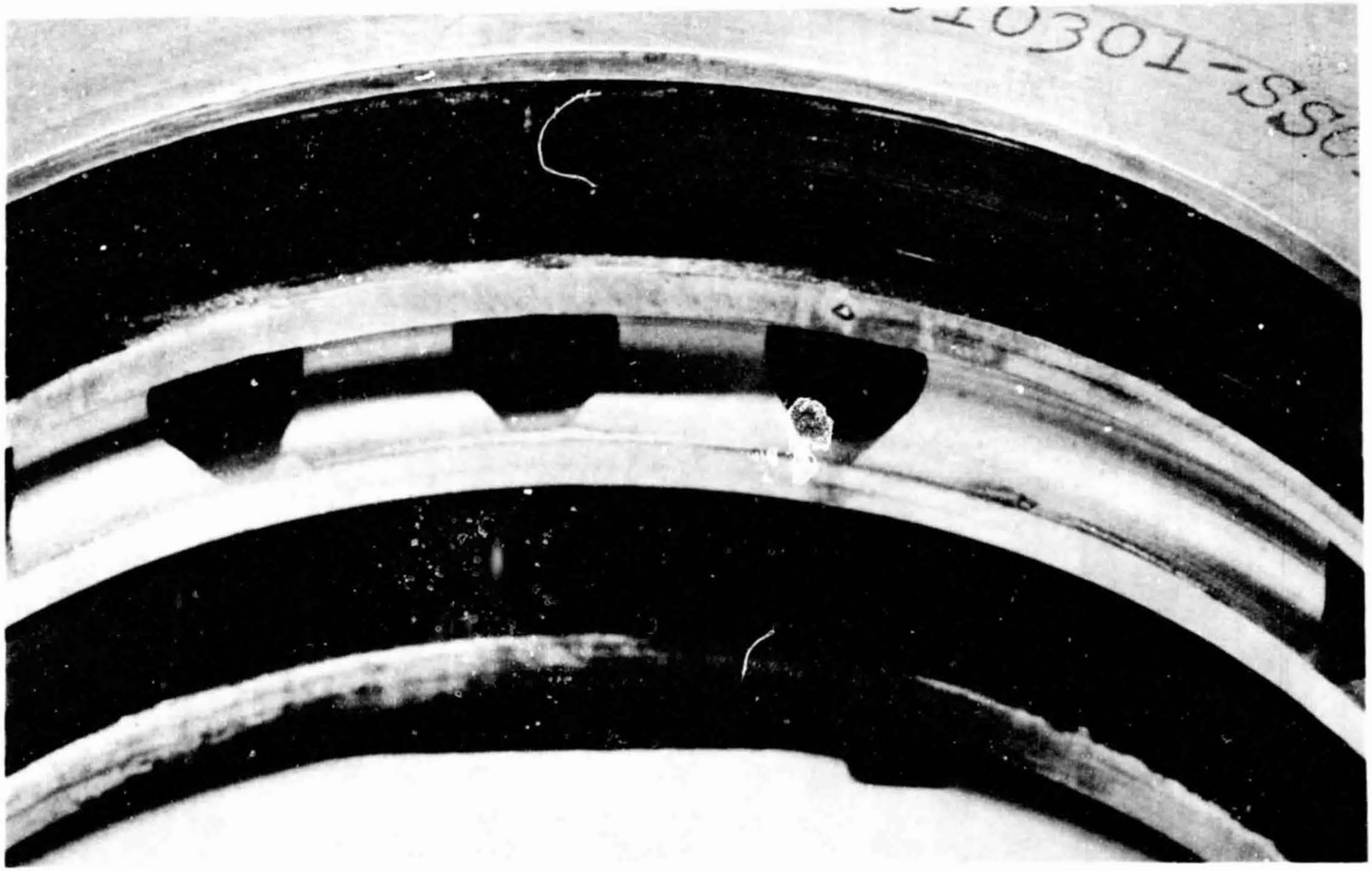


1XY55-4/21/78-C1G

Figure 49. Pump End Assembly, P/N 99RS010309,
Build 9, Posttest 107

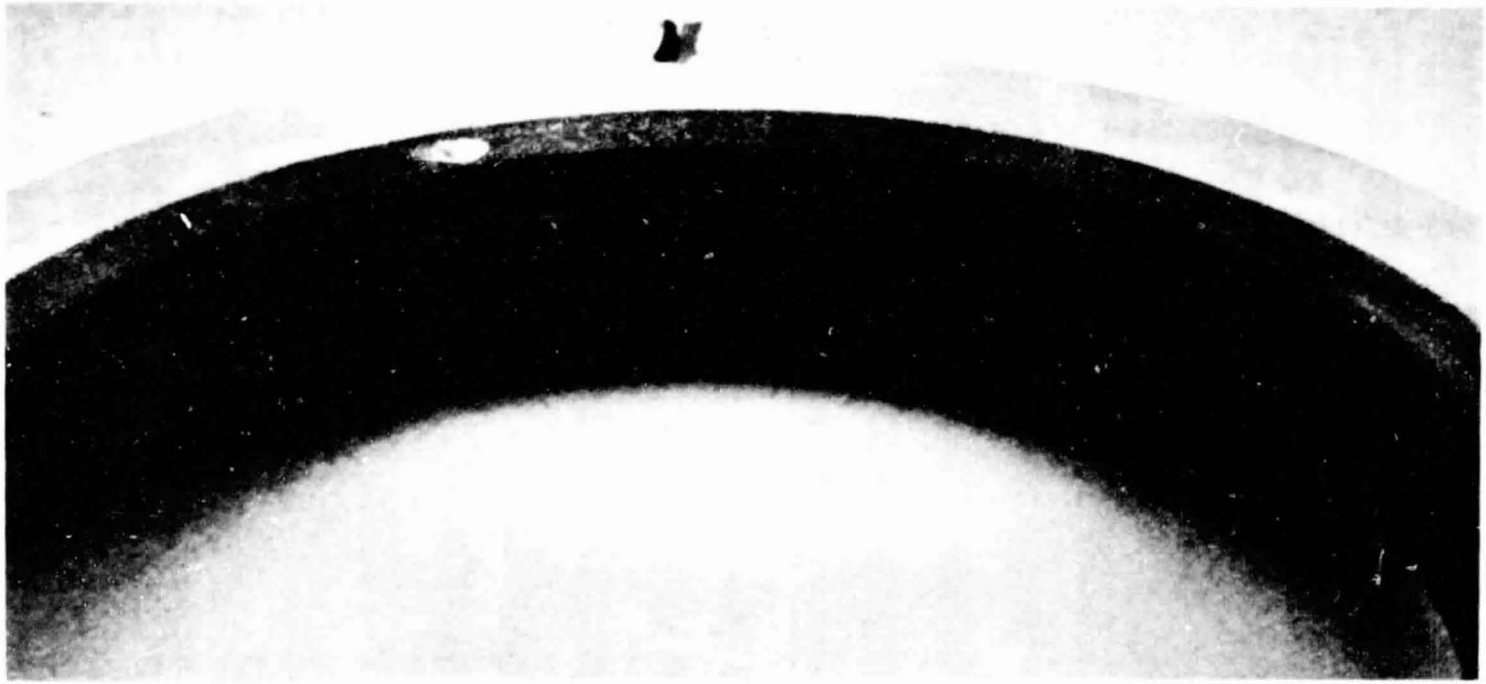
1XY55-4/21/78-C1A

Figure 50. Turbine End Assembly Position 1, P/N 99RS010310,
Build 9, Posttest 107



1XY55-4/21/78-C1E

Figure 51. Turbine End Assembly Position 2, P/N 99RS010310, Build 9, Posttest 107



1XY55-4/24/78-C1A

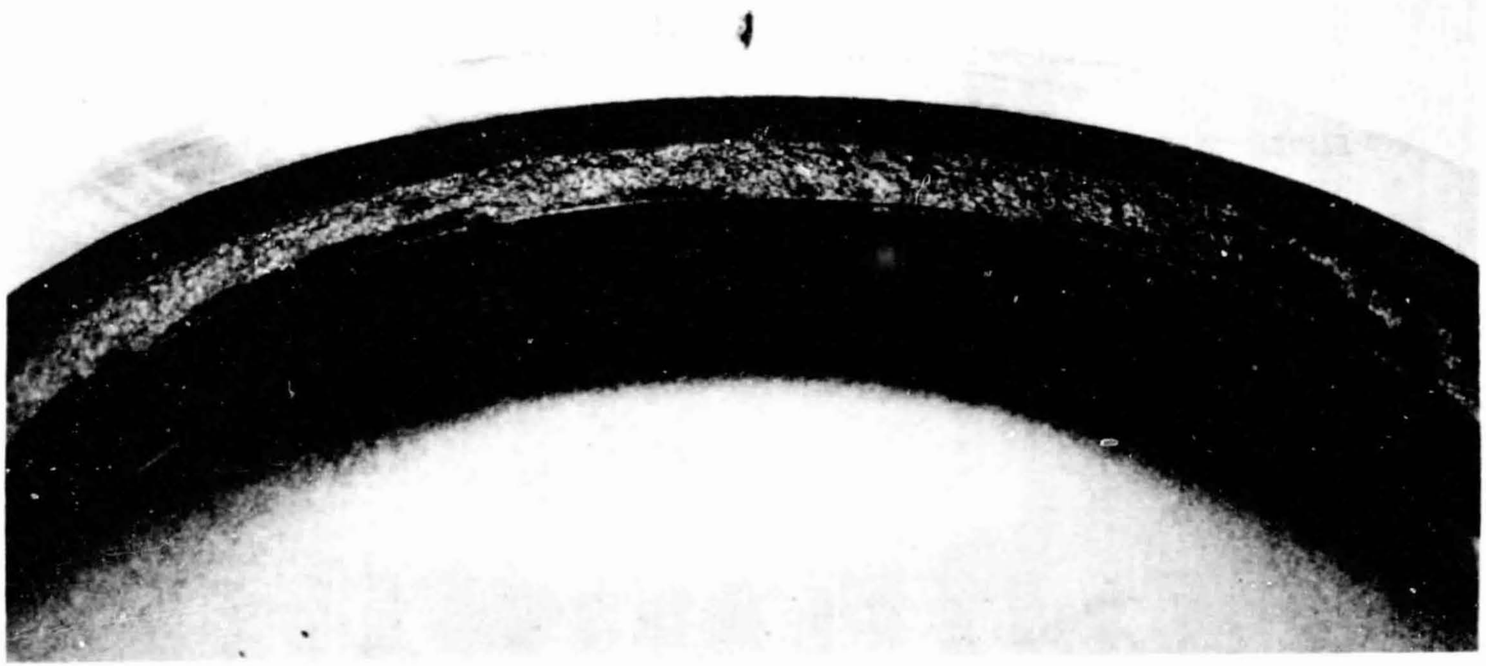
Figure 52. Pump End Primary Seal Ring Position 1, P/N 99RS010302, S/N 067605, Build 9, Posttest 107

1XY55-4/24/78-C1C

Figure 53. Pump End Primary Seal Ring Position 3, P/N 99RS010302, S/N 067605, Build 9, Posttest 107

1XY55-4/24/78-C1E

Figure 54. Pump End Secondary Seal Ring, P/N 99RS010304,
S/N 067605, Build 9, Posttest 107

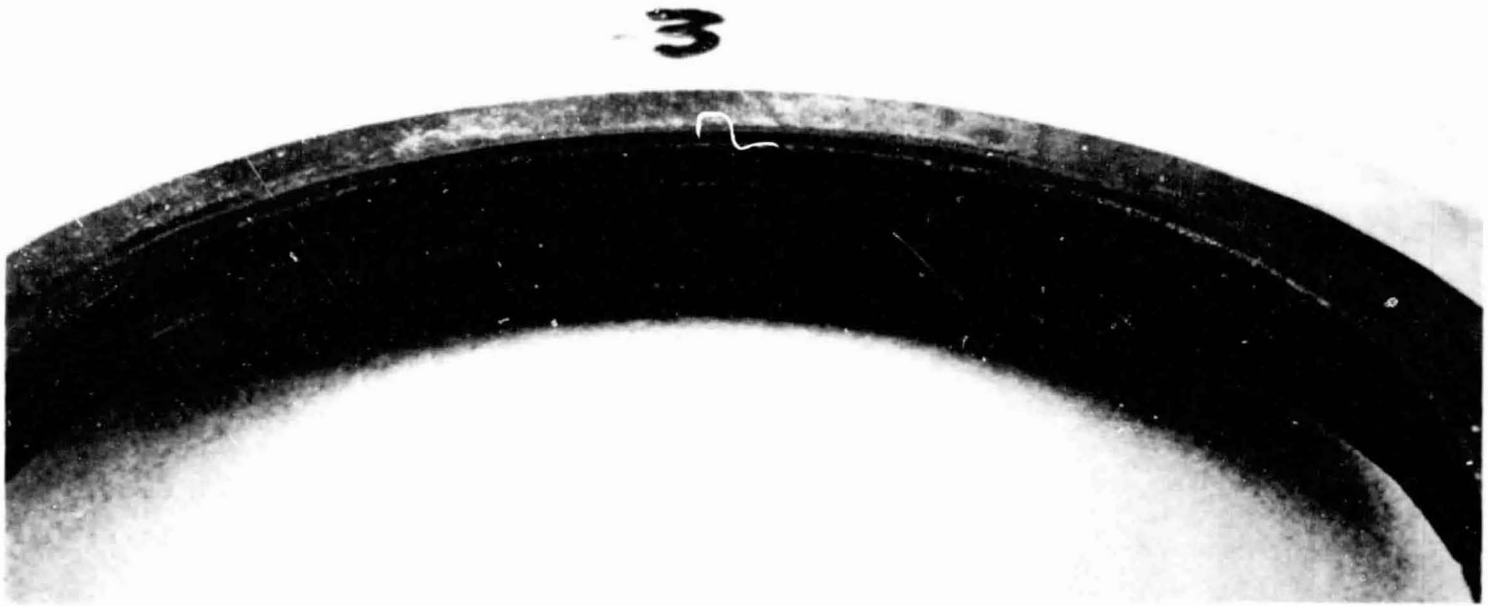


1XY55-4/24/78-C1G

Figure 55. Turbine End Primary Seal Ring Position 1, P/N 99RS010303, S/N 067605
Build 9, Posttest 107

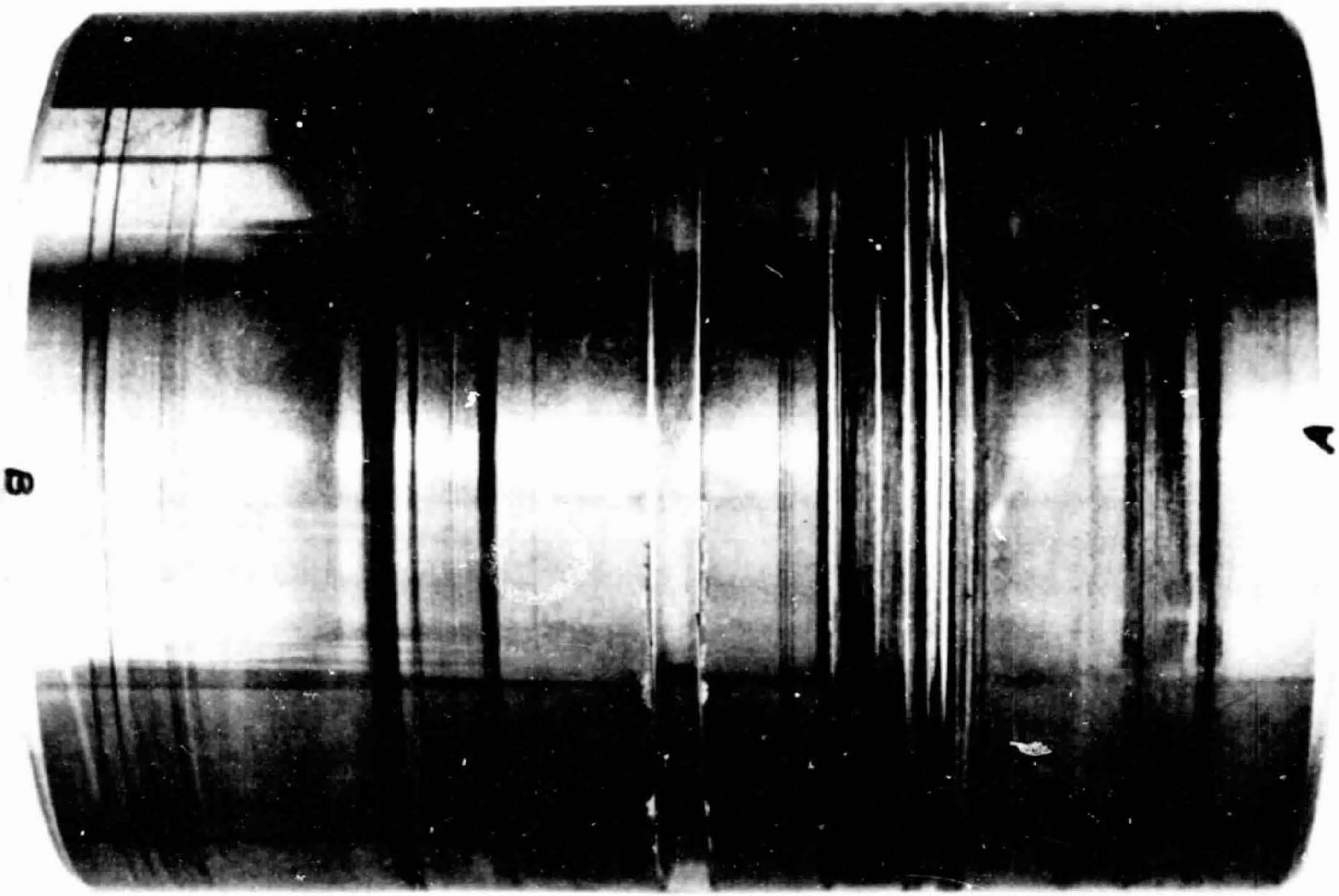
1XY55-4/24/78-C1H

Figure 56. Turbine End Primary Seal Ring Position 3, P/N 99RS010303, S/N 067605, Build 9, Posttest 107



1XY55-4/24/78-C1I

Figure 57. Turbine End Secondary Seal Ring, P/N 99RS010305, S/N 067604, Build 9, Posttest 107



SECONDARY PRIMARY PRIMARY SECONDARY

PUMP END TURBINE END

1XY55-4/24/78-C1F

Figure 58. Mating Ring Sleeve, P/N RS005092X-005, S/N 3, Build 9, Posttest 107

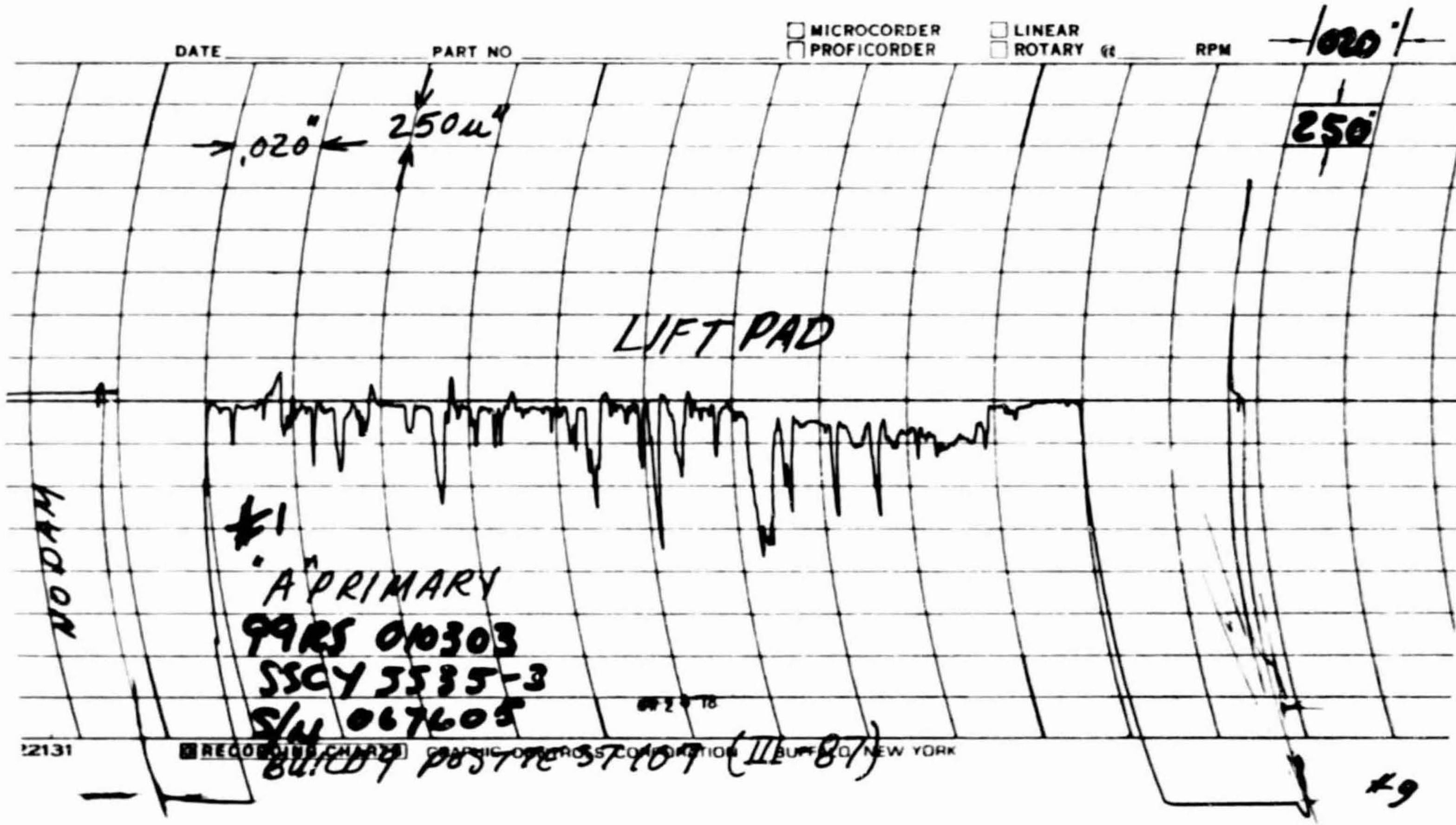


Figure 59. Surface Profile Trace Turbine End Primary Seal Lift Pad 1, P/N 99RS010303, S/N 05, Build 9, Posttest 107

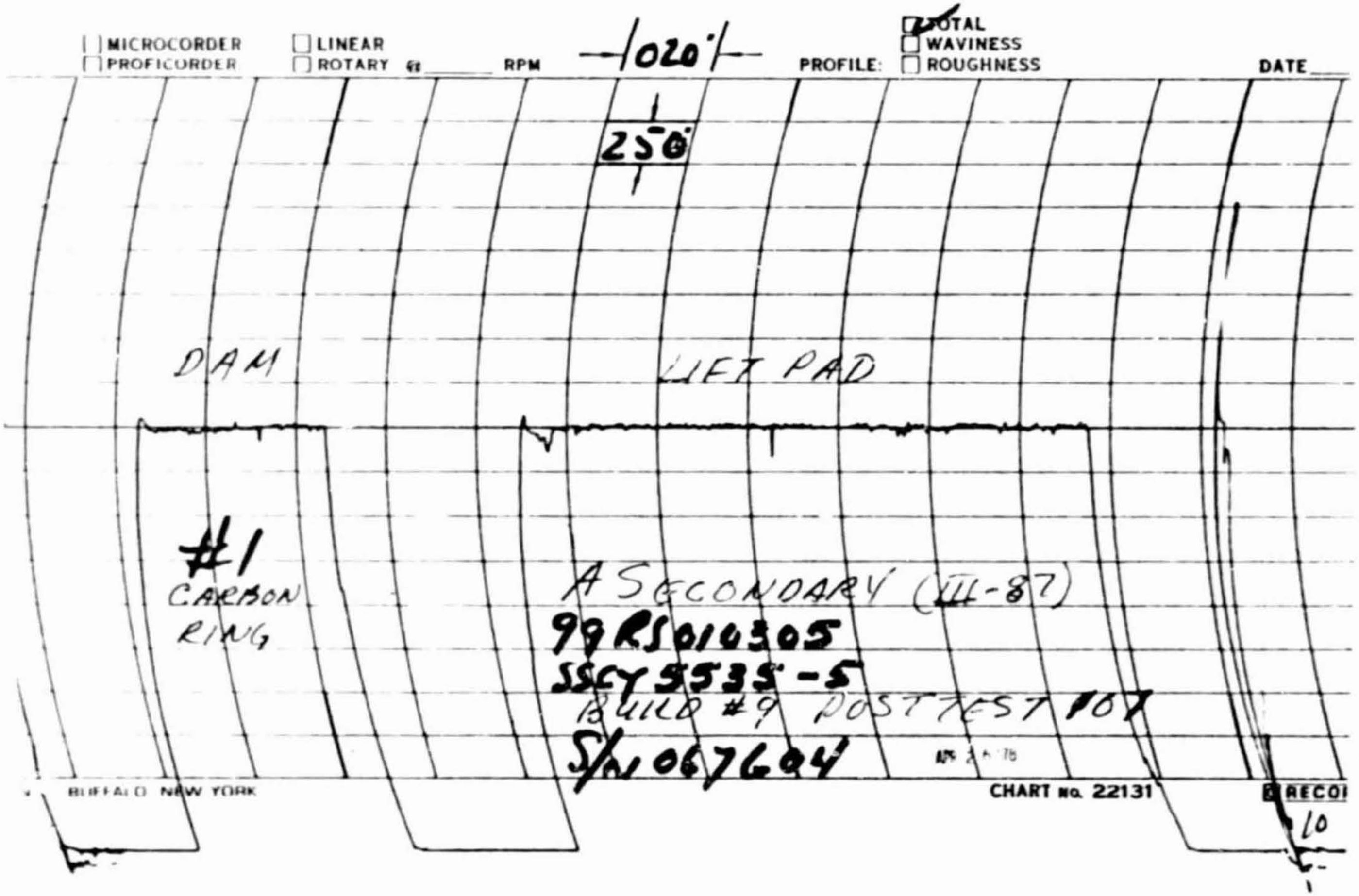


Figure 60. Surface Profile Trace Turbine End Secondary Seal Lift Pad 1, P/N 99RS010305, S/N 04, Build 9, Posttest 107

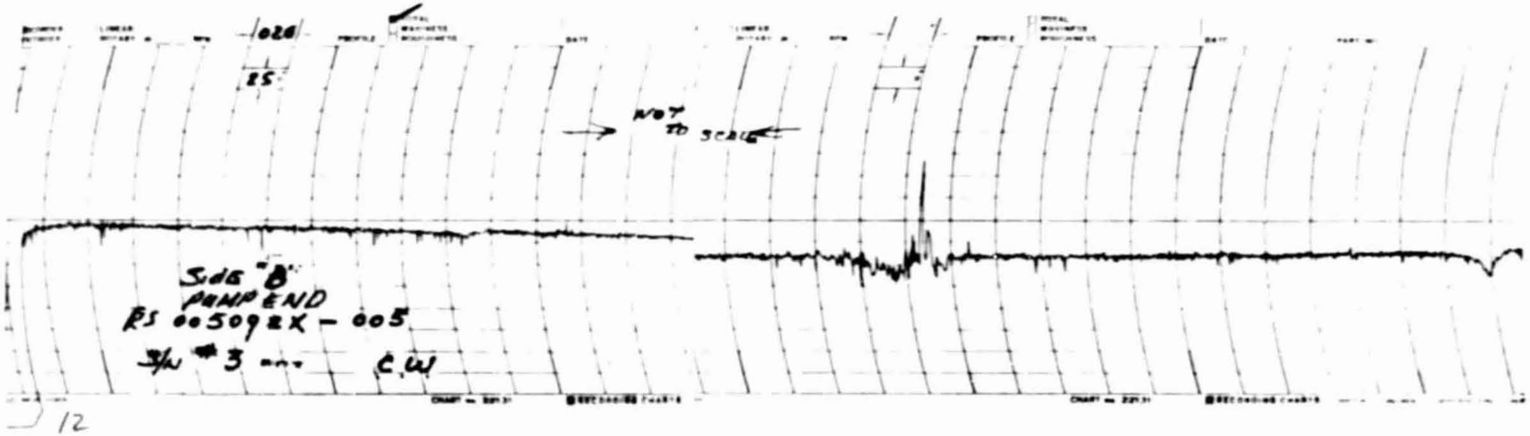


Figure 61. Surface Profile Trace of Tester Mating Ring Sleeve Pump End, P/N RS005092X-005, S/N 3, Build 9, Posttest 107

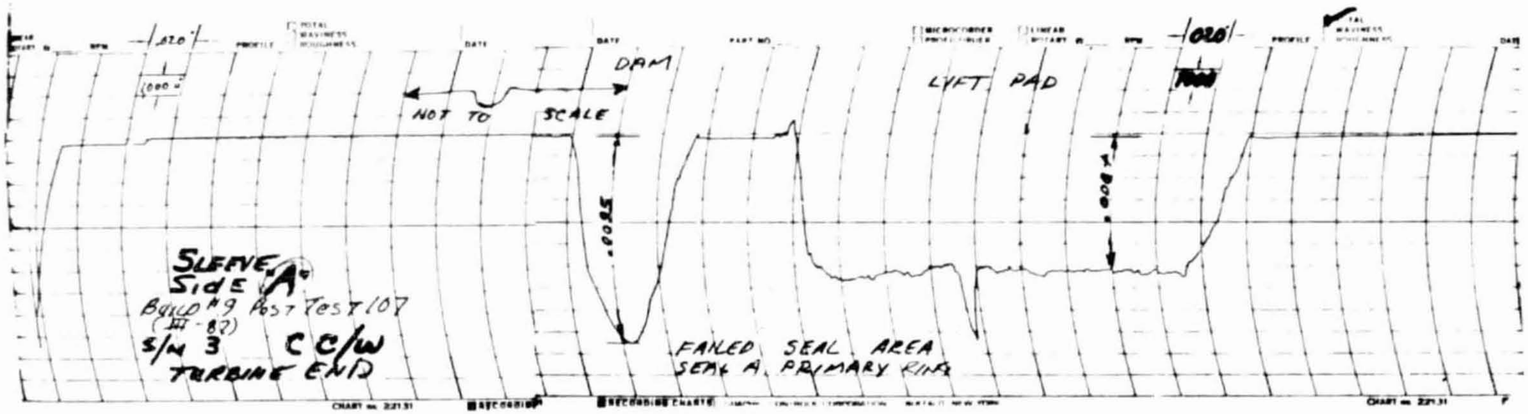


Figure 62. Surface Profile Trace of Tester Mating Ring Sleeve Turbine End, P/N RS005092X-005, S/N 3, Build 9, Posttest 107

A summary of seal ring diametral wear is given in Table 8 . The lift pads were completely worn away on the turbine end primary and secondary seal rings. The wear on the pump end seal lift pads varied from .00000508 to .00002032 m (.0002 to .0008 in.) with some of the pads completely worn away. A summary of the lift pad post test depths is given in Table 8 .

The sealing dam nose height on the side surface of the carbon ring did not change significantly from the assembly dimensions, except the turbine end primary seal which was broken away. The secondary seal rings were both worn on the axial face of the dam with a lip extending inside of the housing diameter. The axial nose height at disassembly is given below:

SEAL	TURBINE END		PUMP END	
	PRIMARY	SECONDARY	PRIMARY	SECONDARY
NOSE HEIGHT M (IN.)	BROKEN	.0003302(.013)	.0005842(.023)	.00032512(.0128)

The mating ring ring sleeve rub pattern appeared the same as pretest 081, except the turbine end primary seal ring area surface was worn .0002413 M(.0095 in.) at the dam location and .0001651 M (.0065 in.) at the lift pad location.

Failure analysis of the turbine end primary seal carbon ring indicated that the dam fracture occurred due to erosion of the upstream edge of the dam. The erosion apparently weakened the carbon dam until it broke away. Pretest 081 erosion was .000762 to .000889 m (.030 to .035 in.). Visual inspection indicated that the fracture started near the base of the dam in the circumferential vent channel between the lift pads and the dam. (Ref: Fig. 9 and 10 May 1978 monthly report RMME 8193-5166). The radius in the bottom of the vent channel measured .000381 to .000508 m(.015 to .020 in.), indicating that the fracture was not initiated by stress concentration from a sharp corner.

The failure analysis revealed that the wave spring was installed on the wrong side of the seal ring; however, dimensional inspection indicated that the spring inside diameter would not interfer with the seal dam.

As a result of the failure caused by erosion damage and wear due to shaft rubbing, it was concluded that a change to a hydrostatic convergent tapered bore design would decrease both the rubbing and erosive wear. An analysis by NASA showed a significant increase in radial stiffness with the tapered bore design compared to the Rayleigh step design. It is expected that the tapered bore seal ring will have sufficient radial gas film stiffness to center itself on the shaft without rubbing contact. The erosion wear should not be a problem since the narrow dam and vent channels are eliminated.

Testing of the Rayleigh step design was stopped. A hydrostatic convergent tapered bore design was procured. The test program was modified to include a hot (533 K, 500 F) gaseous nitrogen checkout test on the new design seals. One set (two seals) of seals will be tested for 8 tests of 2.5 minutes each at progressively higher pressures in 3447378 n/m^2 (500 psi) increments from 3447378 to 25835339 n/m^2 (500 to 3750 psig). The seals will be inspected after the first four tests and at completion. The hot gaseous nitrogen acceleration testing will then be continued on two sets (four seals) of the tapered bore seals at 533 K (500 F) and 25855339 n/m^2 (3750 psia). Each set of seals will be tested for 180 tests of 2.5 minutes each for a total time of 7.5 hours per seal. The seals will be inspected at 2.5 hour intervals.

Discussion – Builds 7 Through 9

A total of 87 tests for 222.12 minutes on 3 Builds (7 through 9) were performed. The tests were run with gaseous nitrogen at 533 K (500 F) and 24682970 n/m (3725 psig). The tester was accelerated through the critical speed and held steady at 3351 rad/sec (32,000 rpm) for 2.5 minutes each test. Testing was terminated due to failure of the turbine end primary seal.

Postbuild 7 inspection revealed that the dam area of the turbine end primary seal ring was eroded away axially and chipped on the upstream edge of the carbon ring. Dam wear varied from 0 to .000762 m (.030 in.). Dam wear was negligible on the other seals.

The lift pads were worn away on the turbine end secondary seal ring. The wear on the other lift pads varied from 0 to .00001524 m(.0006 in.). A summary of seal wear is given in Table 8 .

Postbuild 8 inspection showed some additional wear on the turbine end primary seal ring dam area The lift pads on the turbine end primary seal ring also showed considerable wear. Lift pad wear on the other seal rings varied from 0 to .00000508 m (.0002 in.). The inspection also revealed that the carbon seal rings had rubbed the mating ring sleeve and worn the carbon bore. The wear varied from .00000508 to .000762 m (.0002 to .0030 in.) and was tapered from the turbine end secondary seal down toward the pump end seal.

Postbuild 9 inspection revealed that the turbine end primary seal sealing dam had fragmented and broken away apparently due to erosion of the upstream, edge of the dam. The lift pads were completely worn away on the turbine end primary and secondary seal rings. The pump end seals appeared to be in satisfactory condition except for some lift pad erosion and wear.

Plots of the Rayleigh step seal total leakage versus time and the drain cavity pressures versus time for tests 021 through 107 are shown in Fig. 63 and 64.

As a result of the failure caused by excessive wear due to shaft rubbing it was decided to change to a hydrostatic tapered bore design. The test program was modified to include testing of the new design.

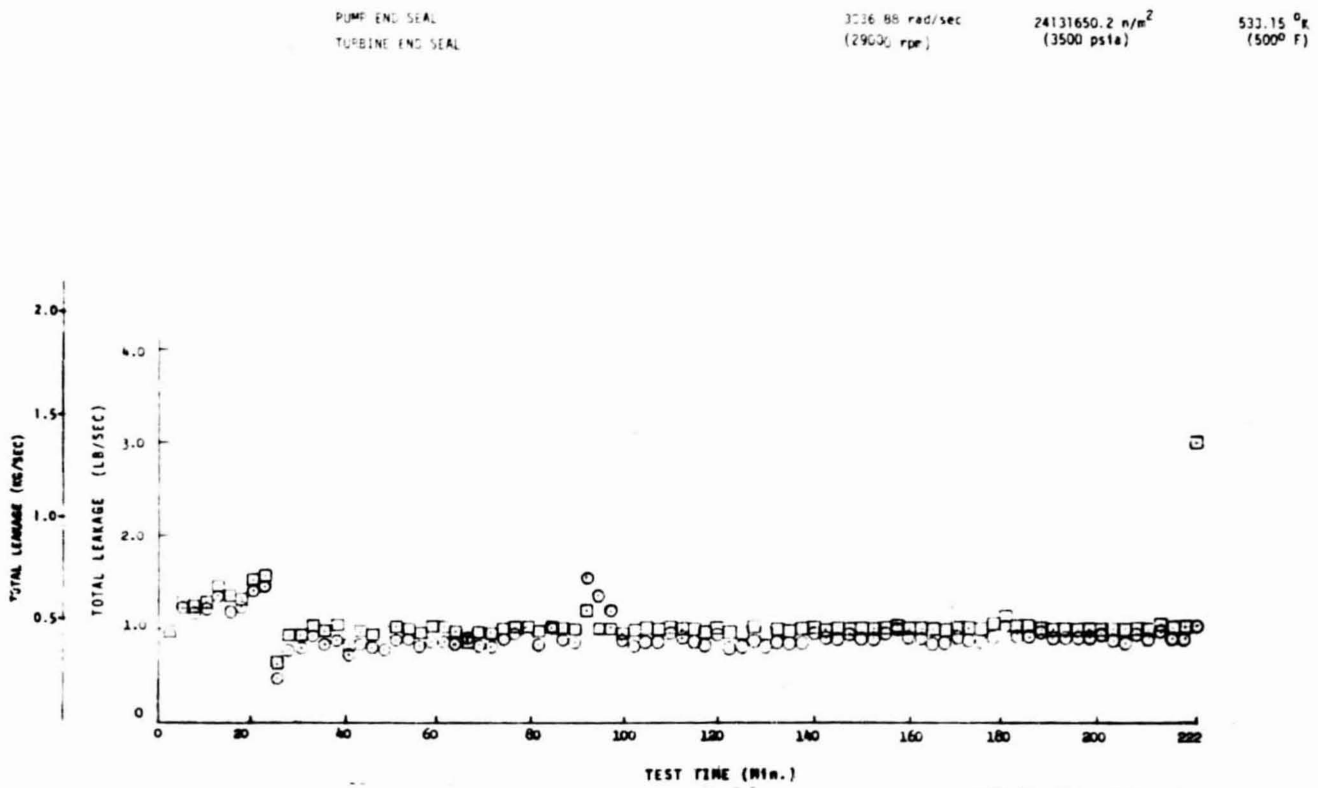


Figure 63. Rayleigh Step Seal Total Leakage vs Test Time, Tests 021-107

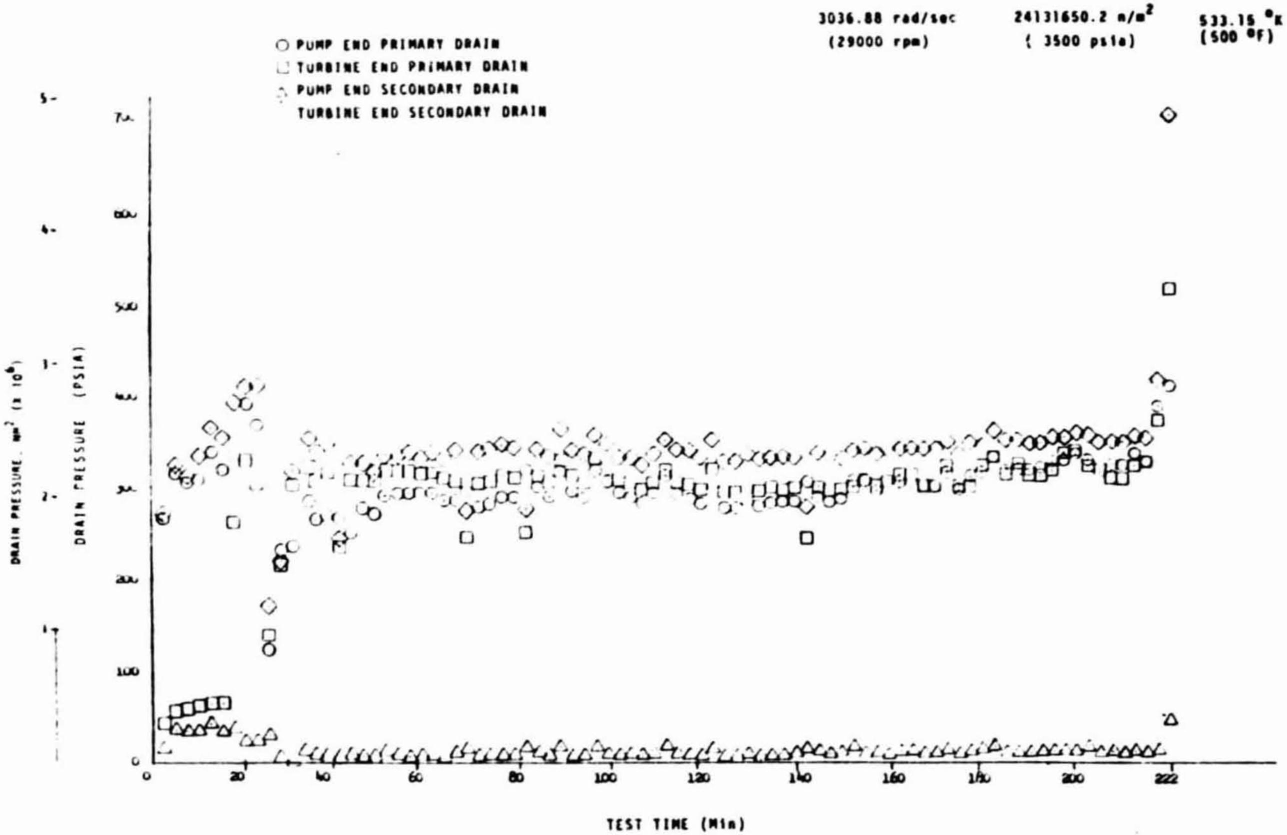


Figure 64. Rayleigh Step Seal Drain Pressure vs Test Time, Tests 021-107

TAPERED BORE SEAL HOT GASEOUS NITROGEN TESTING

Build 10 Assembly Pretest 108

The tester design was modified to incorporate a small disk on the end of the shaft in place of the dummy turbine wheel. Rebalancing of the system was performed and results indicated that the deflection was reduced to an acceptable value .0000508 to .00005588 m, (.0020 to .0022 in.) peak-to-peak by raising the critical speed above the operating point of 3036 rad/sec (29000 rpm). The shaft deflection was measured to be .00005588 m (.0022 in.) peak-to-peak.

The tester was assembled with the new tapered bore carbon insert seal rings and new seal housings. The seal ring to shaft sleeve diametral clearances at assembly are given below:

	PUMP END SEAL-m (IN.)		TURBINE END SEAL-m (IN.)	
	INLET	OUTLET	INLET	OUTLET
PRIMARY	.0002921 (.0115)	.0002413 (.0095)	.00029972(.0118)	.0002413(.0095)
SECONDARY	.0002032 (.0080)	.00017526(.0069)	.0002413 (.0095)	.0001778(.0070)

Pretest 108 static leakage tests using ambient temperature gaseous nitrogen at 3447378 n/m^2 (500 psi) increments from 3447378 to 19994795 n/m^2 (500 to 2900 psig) was measured. Higher pressure could not be obtained due to facility flow limitations. The results are given in Table 12 .

Test 108 to 111

Test Points 1 through 4 of the hot gaseous nitrogen checkout test series was performed for a total of 10-minute test time. The hot gas pressure was increased in 3447378 n/m^2 (500 psi) increments from 3447378 to 13789514 n/m^2 (500 to 2999 psig(at 3036 rad/sec (29000 rpm). Each test was started at 533 K (500 F) and 3447372 n/m^2 (50 psig. The temperature gradually decreased during the test to approximately 395 K (250 F) due to limited capacity of the heat exchanger. The pressure was increased to the test value after the tester was up to speed. The results are given in Table 12.

The seal performance was satisfactory, except the measured leakage was higher than expected. The results indicate that the operating clearance gap is larger than the theoretical prediction. The measured leakage varied from .1265 kg/sec (.279 lb/sec) at 3619747 n/m^2 (525 psig) to .3823 kg/sec (.843 lb/sec) at 1344476 n/m^2 (1950 psig).

Build 10 Disassembly Posttest 111

Inspection revealed the seals to be in good condition. There was no significant wear, except for the turbine end secondary ring bearing pad. The pad was worn

.00009398 m (.0037 in.) on one side. The inspection summary is given in Table 10. The calculated wear from the pre and post test measurements is given below: (negative wear is result of measurement tolerances)

PUMP END SEAL WEAR-m (IN.)				
	POSITION	INLET	OUTLET	PAD
PRIMARY	1	-.0000127(-.0005)	-.00001016(-.0004)	-.0000127(-.0005)
	2	-.00002032(-.0008)	0	0
	3	-.0000228 (-.0009)	-.0000050 (-.0002)	-.0000127(-.0005)
SECONDARY	1	-.0000025 (-.0001)	-.0000152 (-.0006)	---
	2	-.0000177 (-.0007)	-.0000076 (-.0003)	---
	3	-.0000177 (-.0007)	-.0000279 (-.0011)	---

TURBINE END SEAL WEAR - m (IN.)				
	POSITION	INLET	OUTLET	PAD
PRIMARY	1	-.0000101 (-.0004)	.0000127(.0005)	.0000203 (.0008)
	2	-.0000177 (-.0007)	.0000101 (.0004)	.0000254(.0010)
	3	-.0000736 (-.0029)	-.0000025 (-.0001)	.0000025 (.0001)
SECONDARY	1	-.0000635(-.0025)	.0000431 (-.0017)	.0000939 (.0037)
	2	-.0000431 (-.0017)	-.0000076 (-.0003)	.0000304 (.0012)
	3	-.0000431 (-.0017)	-.0000127(-.0005)	.0000101 (.0004)

The surface profile traces of the seal ring inside diameters and the shaft sleeve surface at the seal ring locations indicate no measurable wear.

Build 11 Assembly Pretest 112

The tester was reassembled with the same hardware that was used on Build 10. No rework or modifications were made.

Tests 112 Through 115

Test points 5 through 8 of the hot gaseous nitrogen checkout test series were performed. The hot gas pressure was increased in 3447378 n/m^2 (500 psi) increments from 17236893 to 24131650 n/m^2 (2500 to 3500 psig) at 533 K (500 F) and 3036 rad/sec (29000 rpm). The results are given in Table 12.

The seal performance was satisfactory, except the measured leakage was higher than expected.

The results indicate that the operating gap is larger than predicted, apparently due to the pressure deflection of the seal ring being less than predicted and/or the thermal growth of the shaft being less than predicted. The most probable cause of the larger gap is the seal ring heating up and expanding radially outward faster than the shaft due to the smaller mass. The data points are taken at the beginning of the test where the gas temperature is maximum. Since the gas temperature gradually decreases during the test, steady-state thermal conditions are not obtained. The measured leakage varied from .5066 kg/sec (1.117 lb/sec) at 17064524 n/m^2 (2475 psig) to .6581 kg/sec (1.451 lb/sec).

Build 11 Disassembly Posttest 115

Inspection revealed the seals to be in good condition with negligible wear, except for the turbine end secondary seal. The bearing pad was worn tapered across the ring with .0002311 m (.0091 in.) wear on one side and negligible wear on the opposite side. The tapered carbon bore was worn from .0000152 to .0000685 m (.0006 to .0027 in.) diametral on the smaller outlet side. The mating ring sleeve surface was worn .000000635 to .000001524 m (.000025 to .000060 in.). The hardware condition is shown in Fig. 65 through 73. The inspection summary is given in Table 10 . The calculated wear from the pre- and posttest measurements is given below: (negative wear is result of measurement tolerances)

PUMP END SEAL WEAR - m (IN.)				
	POSITION	INLET	OUTLET	PAD
PRIMARY	1	-.0000101 (-.0004)	.0000025 (.0001)	.0000025 (.0001)
	2	-.0000025 (-.0001)	.0000050 (.0002)	-.0000406 (-.0016)
	3	.0000050 (.0002)	0	-.0000279 (-.0011)
SECONDARY	1	0	.0000152 (.0006)	.0000279 (.0011)
	2	-.0000177 (-.0007)	-.0000050 (-.0002)	-.0000152 (-.0006)
	3	-.0000152 (-.006)	.0000050 (.0002)	.0000127(.0005)

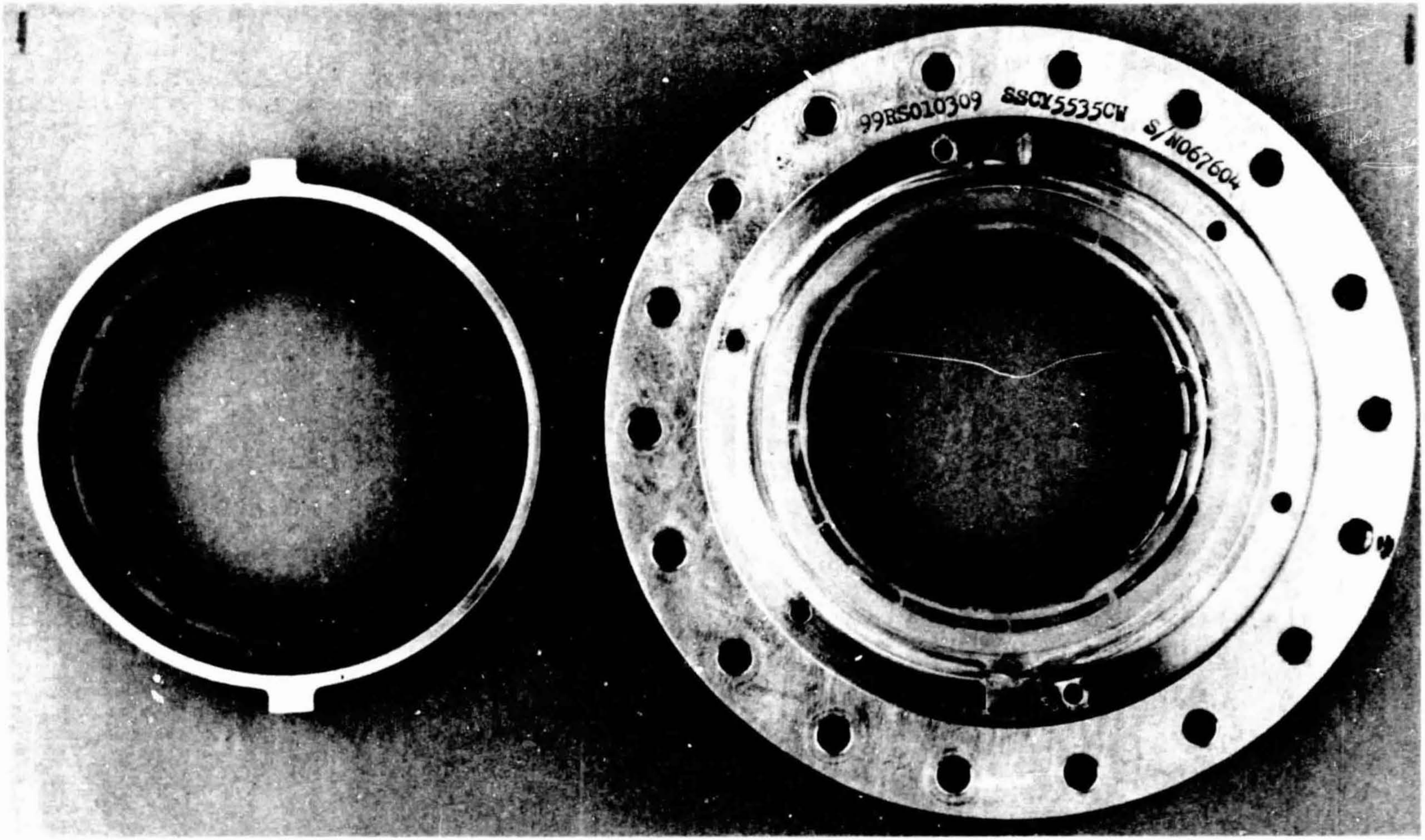


Figure 65. Pump End Primary Seal, P/N 7R0011525, S/N 047906, Build 11, Posttest 115

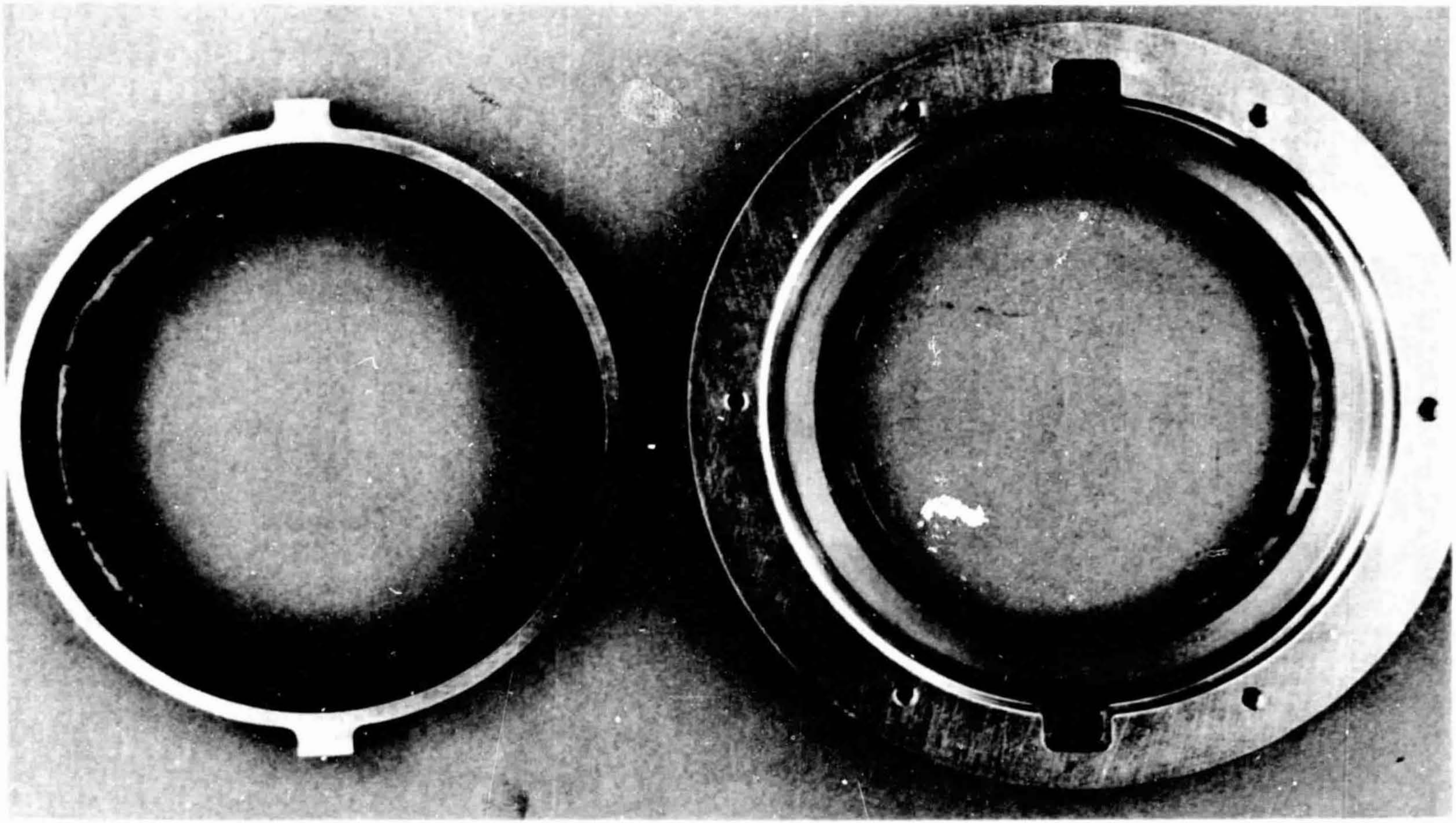


Figure 66. Pump End Secondary Seal, P/N 7R0011526, S/N 047902,
Build 11, Posttest 115

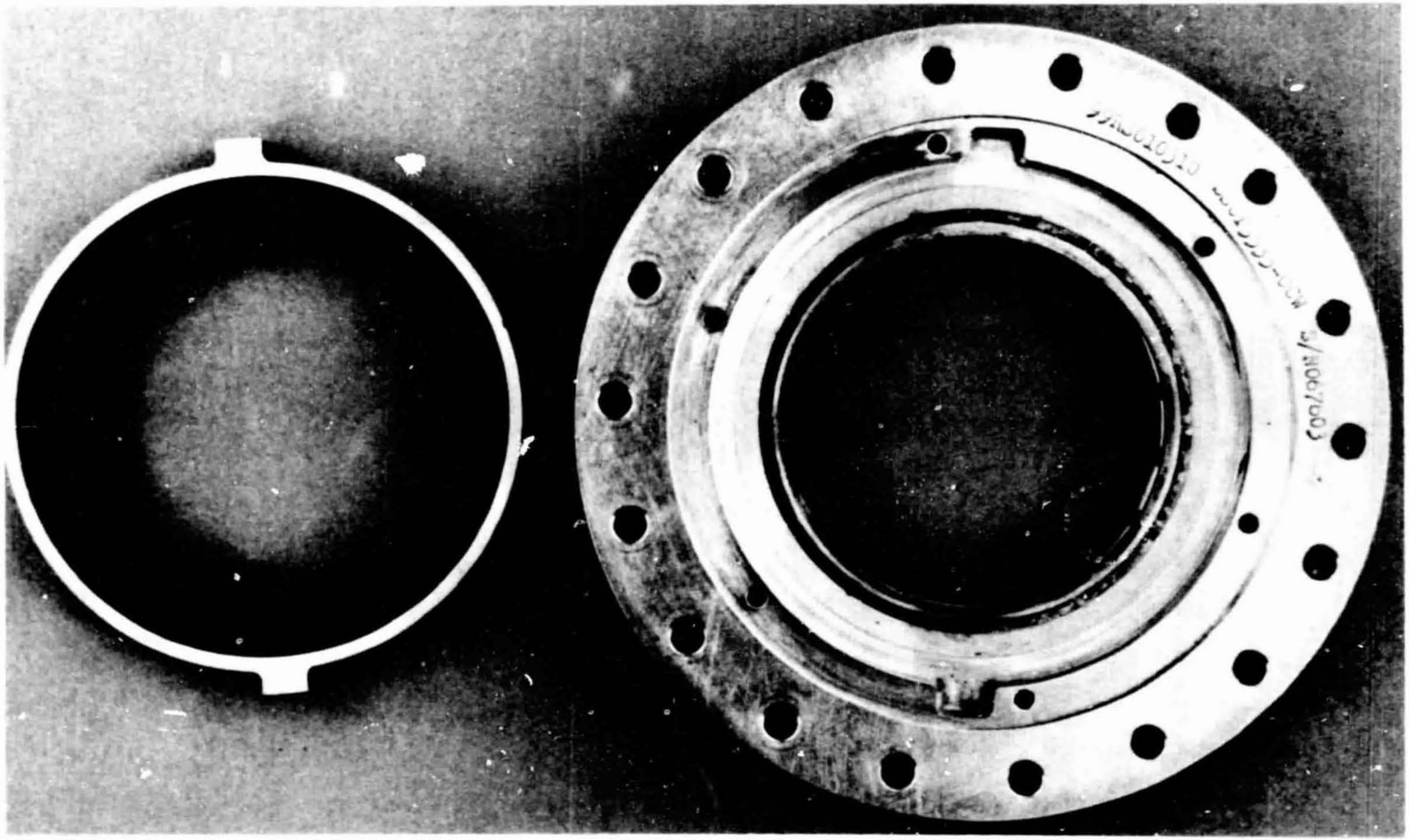


Figure 67. Turbine End Primary Seal, P/N 7R0011525, S/N 047901, Build 11, Posttest 115

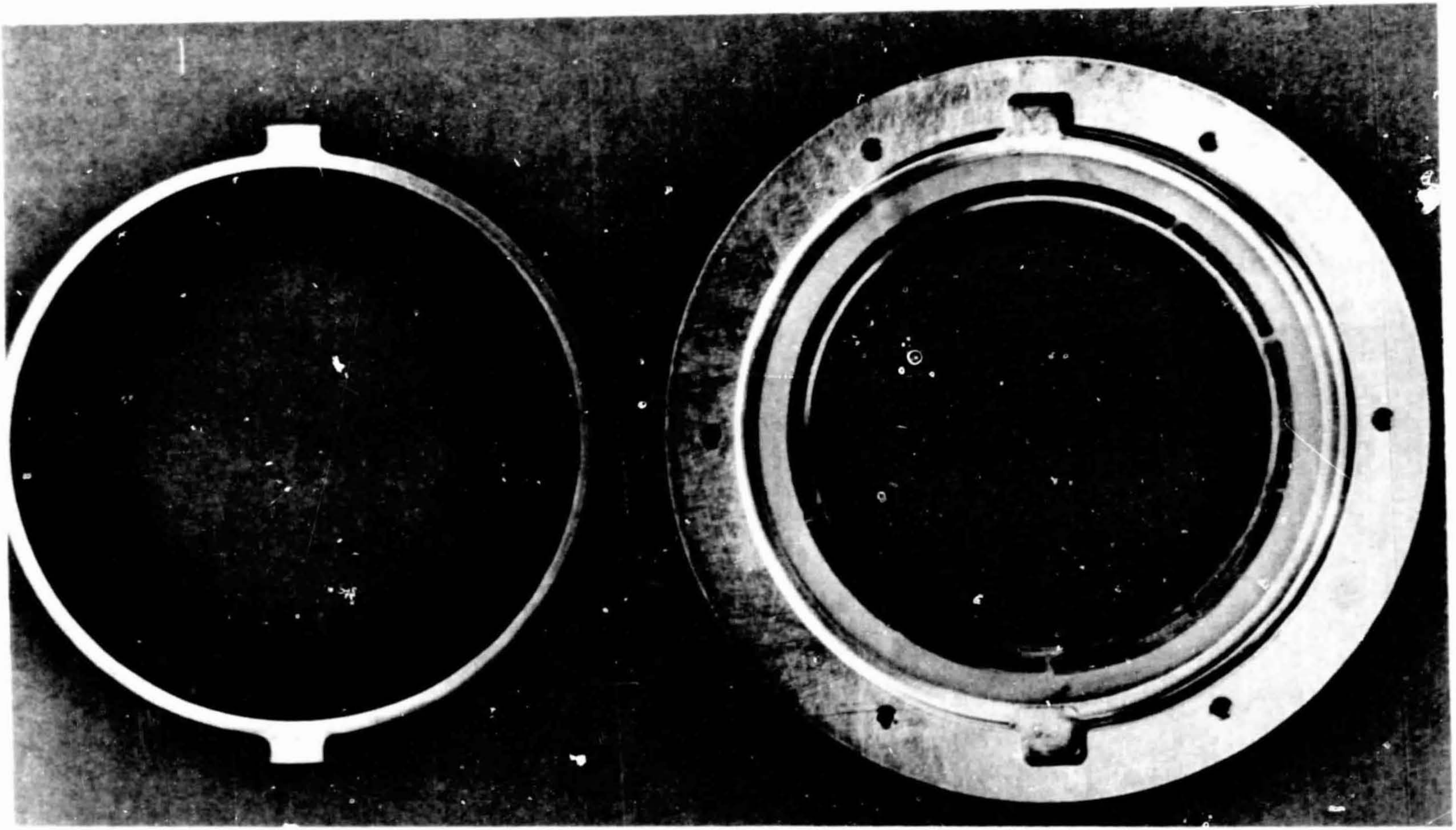


Figure 68. Turbine End Secondary Seal, P/N 7R0011526, S/N 047901, Build 11, Posttest 115

1XY55-7/31/70-C1F

Figure 69. Pump End Primary Seal Ring, P/N 7R0011525, S/N 047906, Build 11, Posttest 115

1XY55-7/31/79-C1G

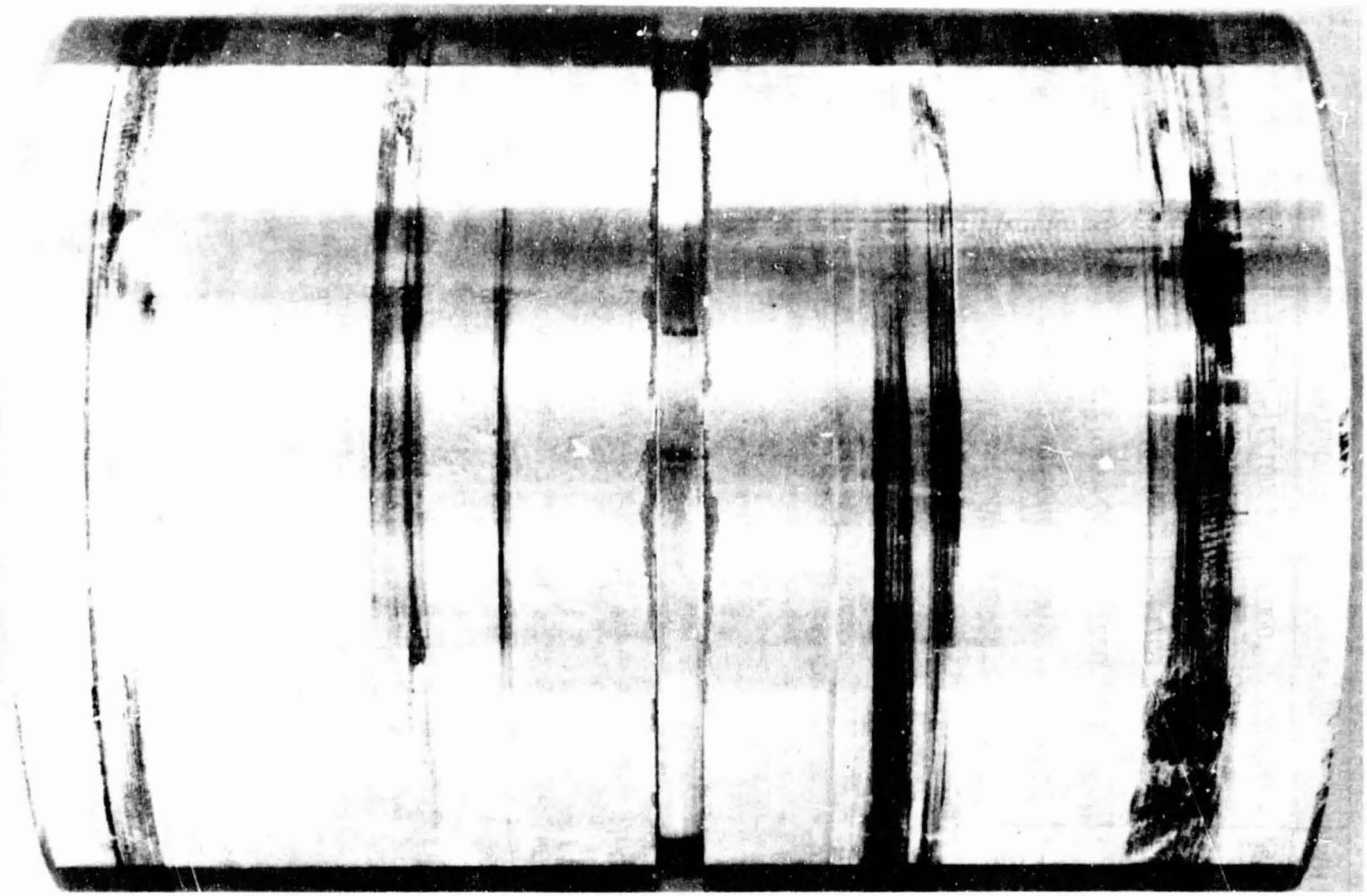
Figure 70. Pump End Secondary Seal Ring, P/N 7R0011526, S/N 047902, Build 11, Posttest 115

1XY55-7/31/79-C11

Figure 71. Turbine End Primary Seal Ring, P/N 7R0011525, S/N 047901, Build 11, Posttest 115

1XY55-7/31/79-C1H

Figure 72. Turbine End Secondary Seal Ring, P/N 7R0011526, S/N 047901, Build 11, Posttest 115



PUMP SIDE TURBINE SIDE

Figure 73. Mating Ring Sleeve, P/N RS005092X-005, S/N 4
Build 11, Posttest 115

TURBINE END SEAL WEAR - m (IN.)				
	POSITION	INLET	OUTLET	PAD
PRIMARY	1	-.0000076 (-.0003)	-.0000127(-.0005)	.0000177 (.0007)
	2	-.0000203 (-.0008)	-.0000076 (-.0003)	.0000177 (.0007)
	3	.0000533 (.0021)	-.0000050 (-.0002)	.0000406 (.0016)
SECONDARY	1	.0000812 (.0032)	.0000685 (.0027)	.0002311 (.0091)
	2	-.0000254(-.0010)	.0000406 (.0016)	-.0000177 (-.0007)
	3	-.0000152 (-.0006)	.0000152 (.0006)	.0000025 (.0001)

The surface profile traces of the seal ring inside diameters indicate no significant wear. The surface profile traces of the mating ring sleeve at the seal contact locations also indicate no significant wear except for slight erosion at the turbine end secondary seal location. The surface profile traces are shown in Fig. 74 through 79. The seal hardware was in satisfactory condition to be used for the acceleration test series.

Discussion — Builds 10 and 11

The static seal leakage using ambient temperature gaseous nitrogen was measured pretest 108 at 3447378 n/m^2 (500 psi) increments from 3447378 to 19994795 n/m^2 (500 to 2900 psig). The results are given in Table 12 . The total leakage varied from .136 kg/sec 3 lb/sec) at 3447378 n/m^2 (500 psig) to .8164 kg/sec (1.8 lb/sec) at 19994795 n/m^2 (2900 psig). The leakage on both seals was approximately the same.

A total of 8 Schedule II tests for 21.1 minutes was performed at 3447378 n/m^2 (500 psi) pressure increments from 3447378 to 24131650 n/m^2 (500 to 3500 psig) at 533 K (500 F) and 3036 rad/sec (29000 rpm). The seals were inspected after the first four tests and at completion. The seals were in good condition with negligible wear, except for the turbine end secondary seal. The bearing pad was worn .00023114 m (.009 in.) and the carbon bore was worn .0000152 to .0000685 m (.0006 to .0027 in.). The mating ring sleeve surface was worn .000000635 to . 000001524 m (.000025 to .000060 in.). The wear was attributed to large radial displacement of the tester shaft at the overhung end. The test data summary is given in Table 12. The hardware summary is given in Table 7. The inspection summary is given in Table 10.

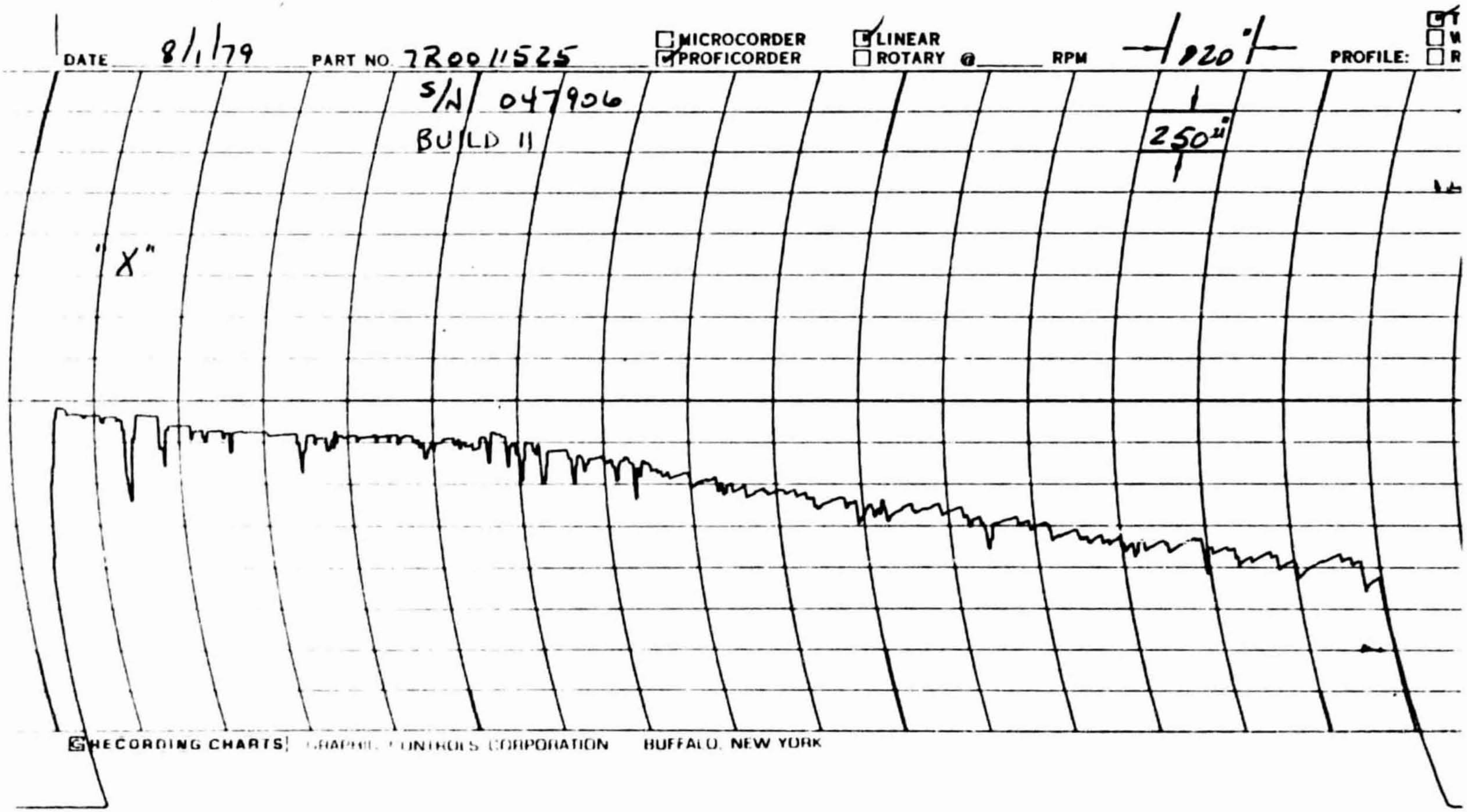


Figure 74. Surface Profile Trace Pump End, Primary Seal Ring, P/N 7R0011525, S/N 047906, Build 11, Posttest 115

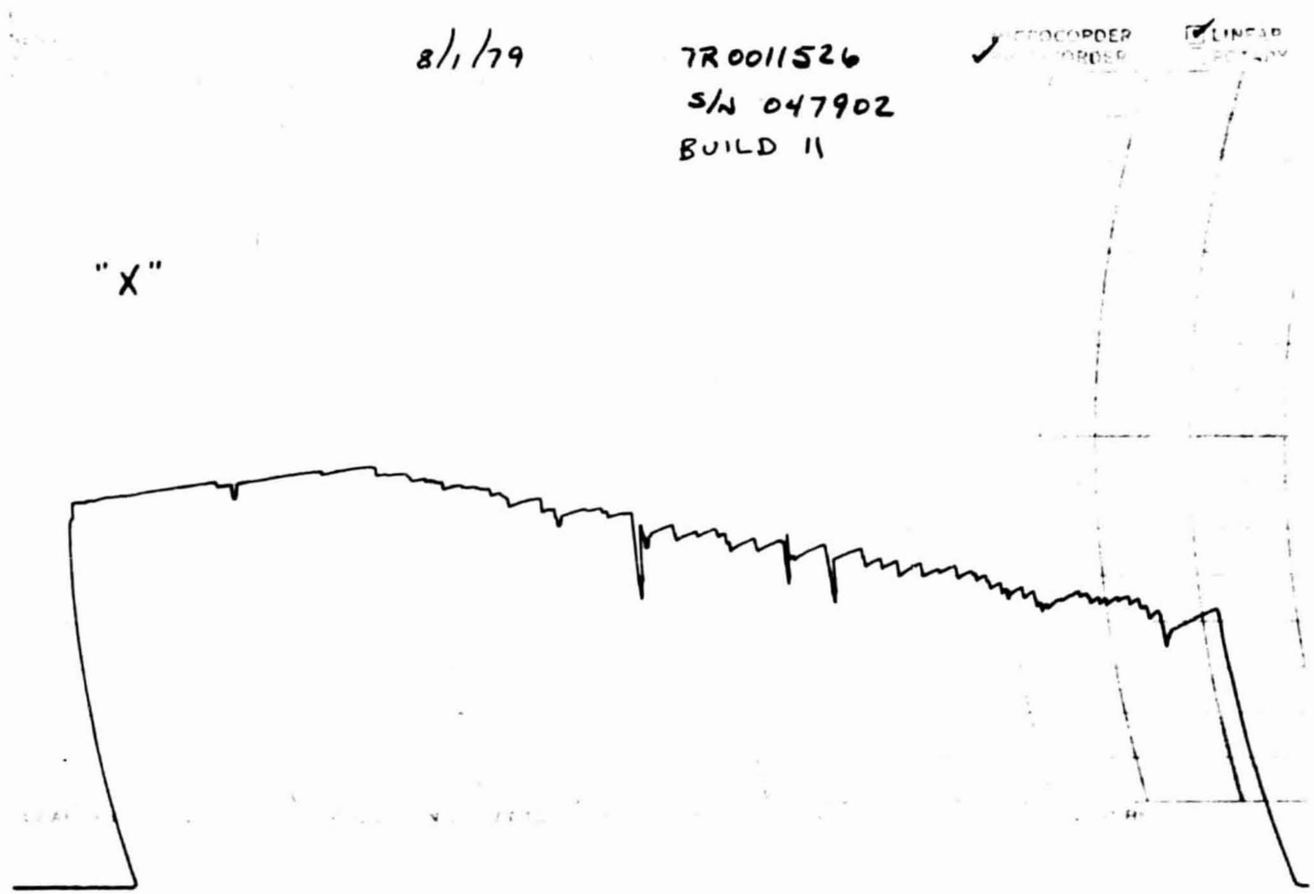


Figure 75. Surface Profile Trace Pump End, Secondary Seal Ring, P/N 7R0011526, S/N 047902, Build 11, Posttest 115

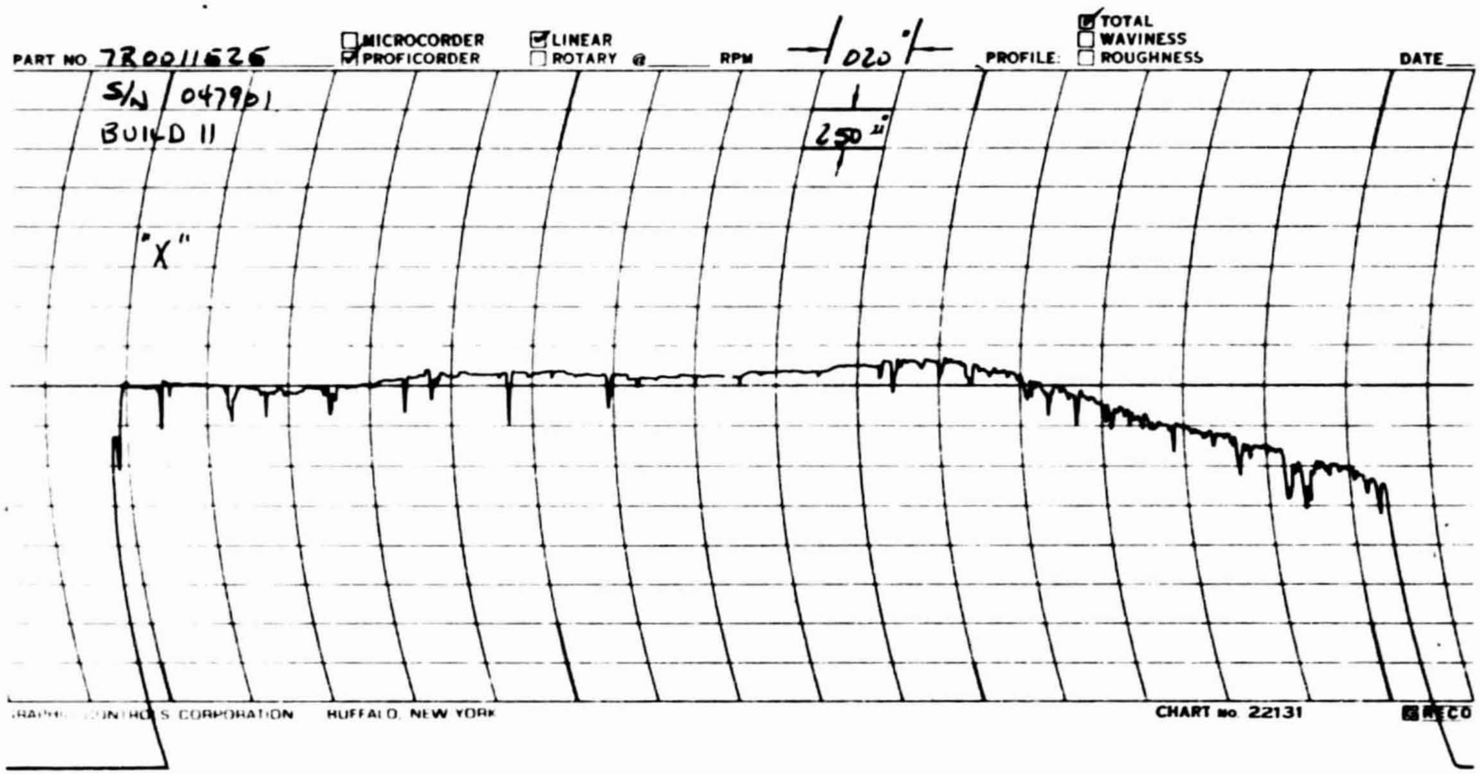


Figure 76. Surface Profile Trace Turbine End, Primary Seal Ring,
P/N 7R0011525, S/N 047901, Build 11, Posttest 115

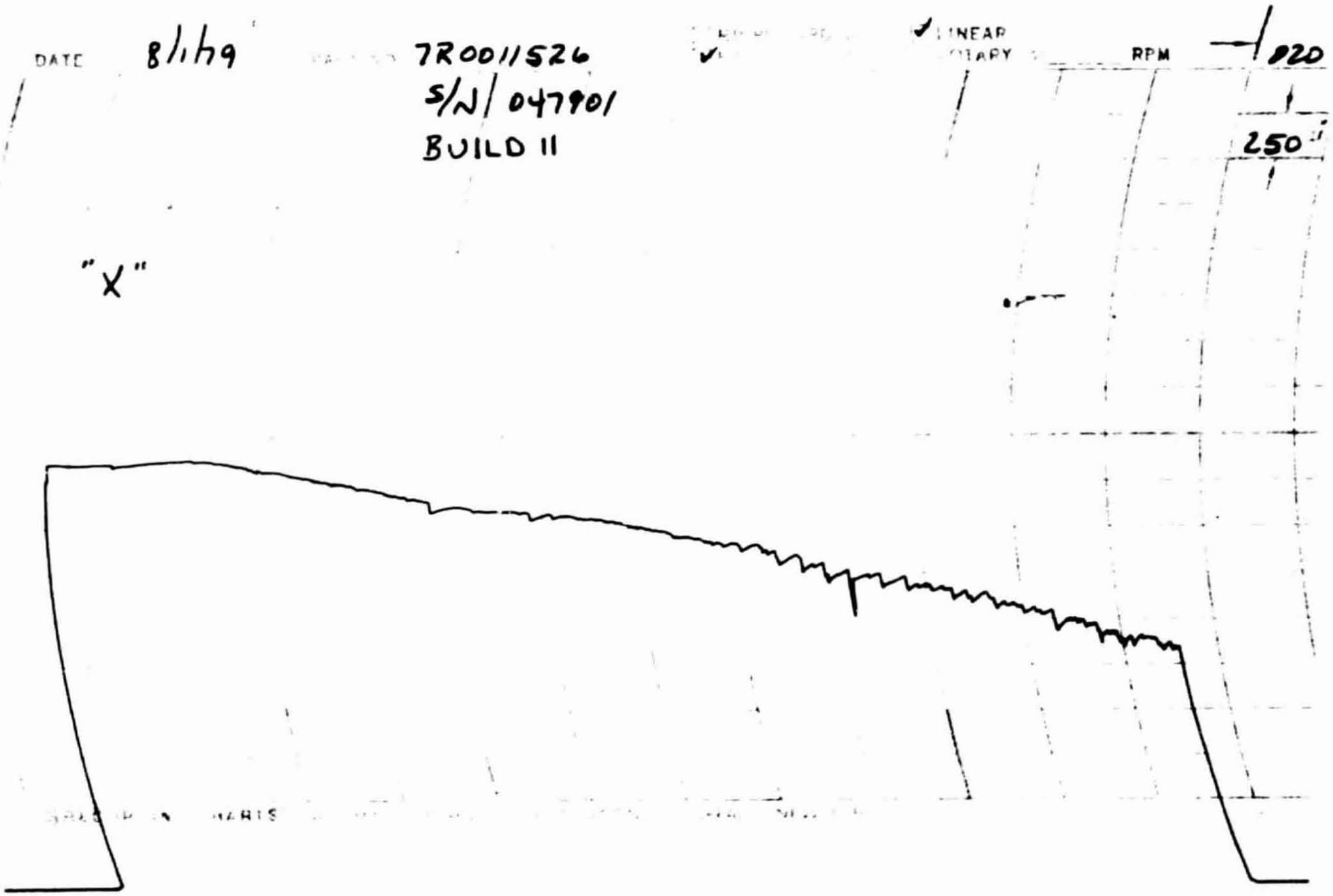
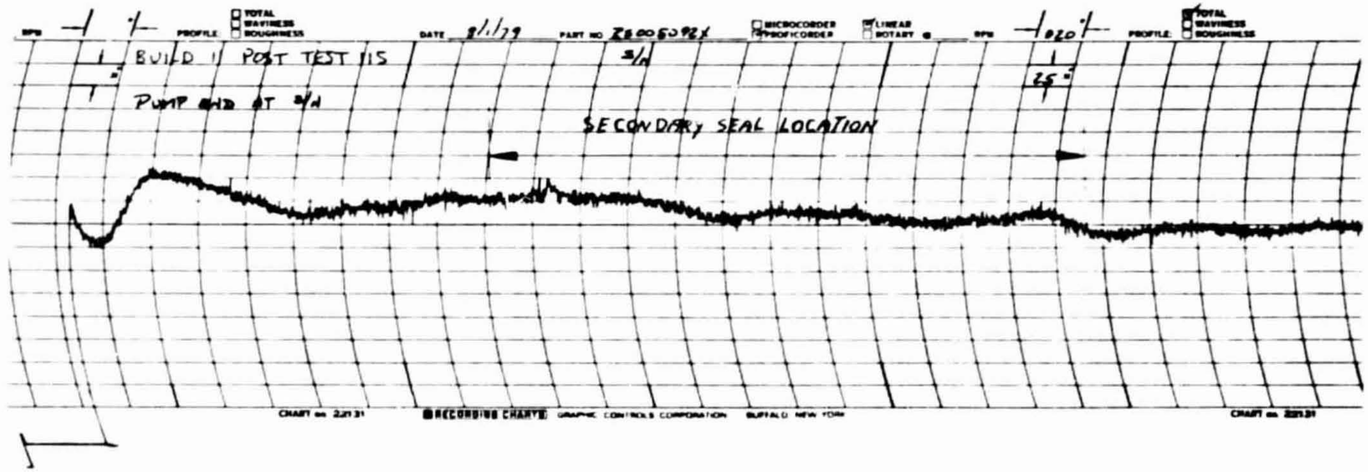
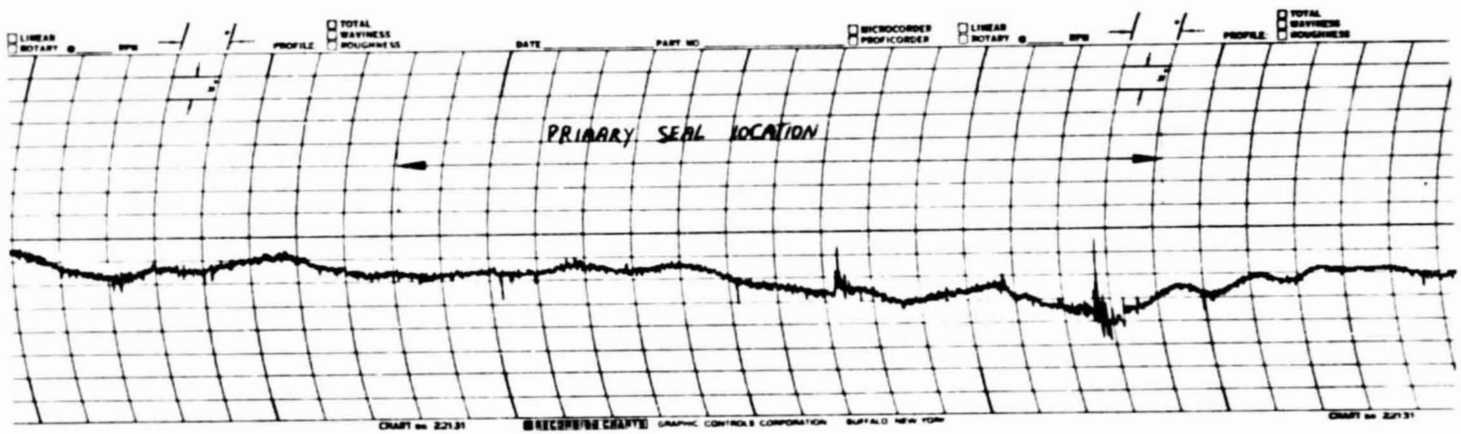


Figure 77. Surface Profile Trace Turbine End, Secondary Seal Ring, P/N 7R0011526, S/N 047901, Build 11, Posttest 115

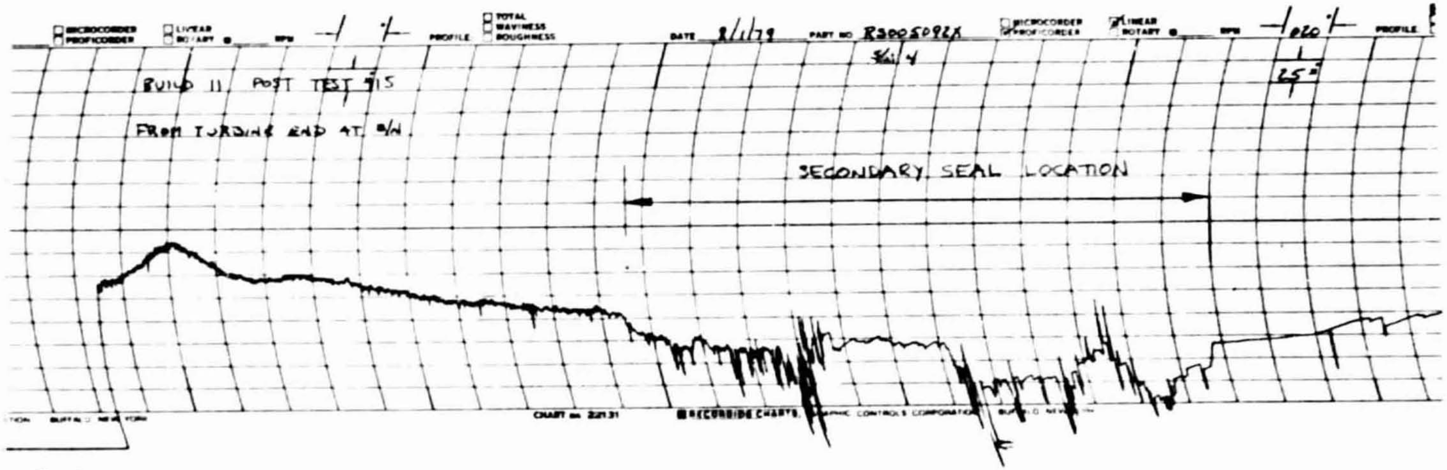


PUMP END SECONDARY SEAL LOCATION

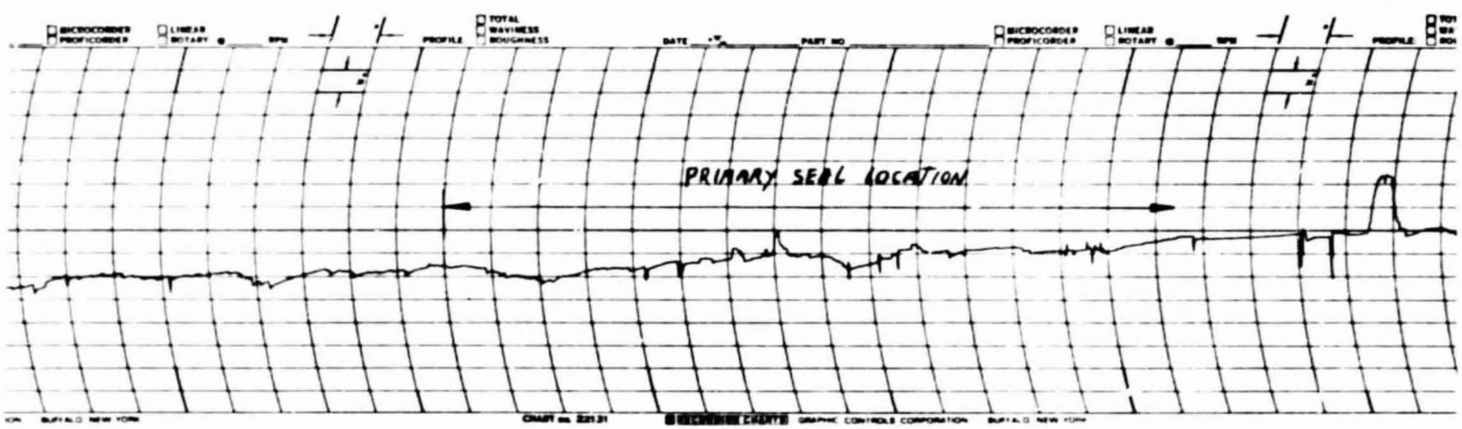


PUMP END PRIMARY SEAL LOCATION

Figure 78. Surface Profile Traces of Tester Mating Ring Sleeve Pump End, P/N RS005092X, S/N 4, Build 11, Posttest 115



TURBINE END SECONDARY SEAL LOCATION



TURBINE END PRIMARY SEAL LOCATION

Figure 79. **Surface Profile Traces of Tester Mating Ring Sleeve Turbine End, P/N RS005092X, S/N 4, Build 11, Posttest 115**

TAPERED BORE SEAL ACCELERATION TESTING

Build 12 Assembly Pretest 116

The tester was reassembled with the same seal hardware used on Build 11.

Tests 116 through 158

The hot gaseous nitrogen acceleration test series was initiated. The shaft speed was ramped to 3036 rad/sec (29000 rpm) in 10 seconds or less. The seal pressure was increased from 344737 to 24131650 n/m^2 (50 to 3500 psig) during the same period. The hot gas temperature was 533K (500 F) at start and gradually decayed to approximately 366K (200 F) at cutoff. A total of 43 tests of 2.5 minutes duration each for 107.5 minutes was performed. The results are given in Table 12.

The testing was terminated due to a sudden increase in vibration and leakage caused by a tester bearing failure. The seal performance was satisfactory with measured leakage rates from approximately .6350 to .7257 kgs/sec (1.4 to 1.6 lb/sec).

Build 12 Disassembly Posttest 158

Inspection revealed the turbine end tester bearing to be failed. The fiberglass-Teflon cage was broken-up and the balls were excessively worn. Investigation indicated that the cage failed due to softening caused by the high temperature at the turbine end of the tester. The tests utilized bearings which were originally designed for operation in liquid oxygen. Special silver-plated 4130 steel cages were fabricated as a replacement for the fiberglass-Teflon cages to withstand the high temperature.

The seals were in good condition with negligible wear, except for the turbine end secondary seal. The axial sealing dam and bearing pad was worn an additional .0003022 m (.0119 in.) for a total of .0003937 m (.0155 in.). The pad was worn with a taper across the ring. The pad height remaining was .0000635 m (.0025 in.) on one side and .00024892 m (.0098 in.) opposite. The carbon bore was worn .0001295 to .00027178 m (.0051 to .0107 in.) diametral on the inlet and .000076 to .0002463 m (.003 to .0097 in.) diametral on the outlet. The hardware condition is shown in Fig. 80 through 84. The inspection summary is

Figure 80. Pump End Primary Seal Ring, P/N 7R0011525, S/N 047906, Build 12, Posttest 158

Figure 81. Pump End Secondary Seal Ring, P/N 7R0011526, S/N 047902, Build 12, Posttest 158

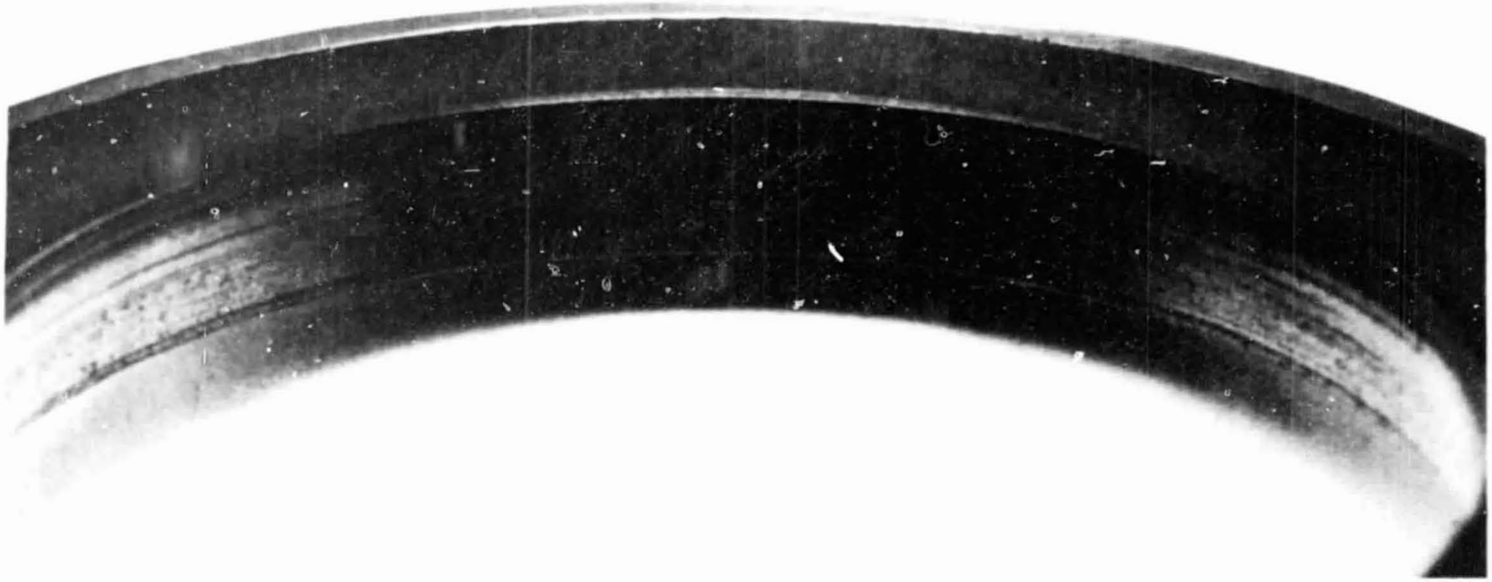


Figure 82. Turbine End Primary Seal Ring, P/N 7R0011525, S/N 047901, Build 12, Posttest 158

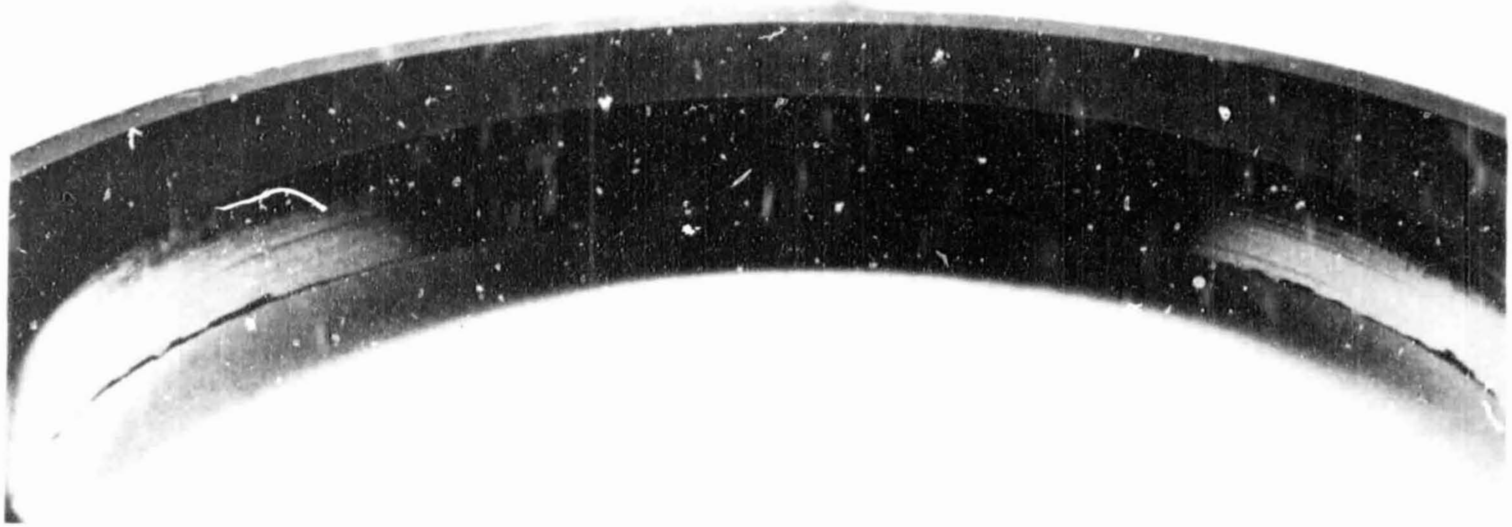


Figure 83. Turbine End Secondary Seal Ring, P/N 7R0011526, S/N 047901, Build 12, Posttest 158

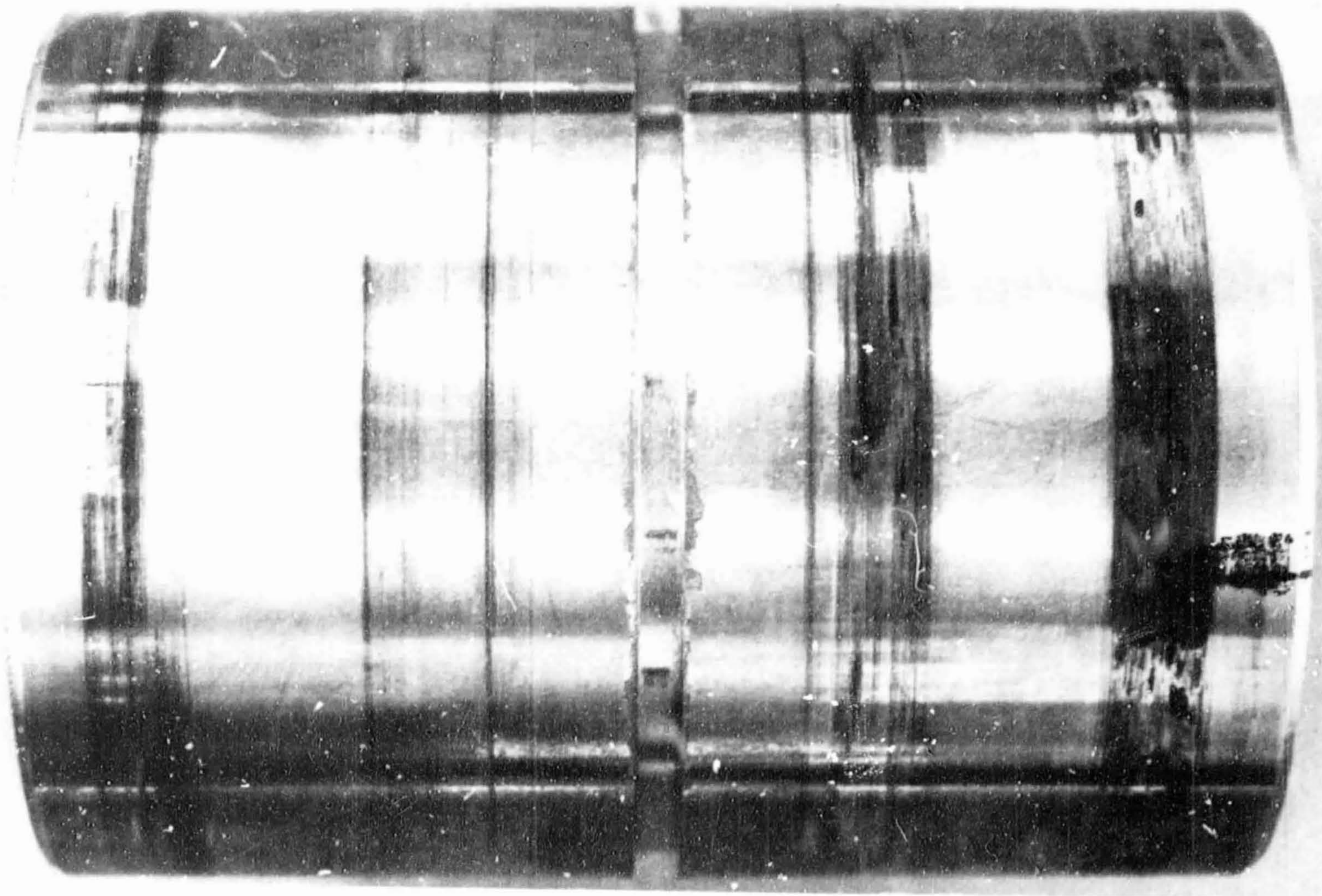


Figure 84. Mating Ring Sleeve, P/N RS005092X-005, S/N 4, Build 12, Posttest 158

given in Table 10. The calculated wear from the pretest 116 and posttest 158 measurements is given below:

PUMP END SEAL WEAR PRETEST 116 TO POST TEST 158-m (IN.)			
POSITION	INLET	OUTLET	PAD
PRIMARY 1	-.0000101 (-.0004)	.0000304 (.0012)	.000025 (.0001)
2	.0000152 (.0006)	.0000025 (.0001)	.0000304 (.0012)
3	.0000076 (.0003)	.0000076 (.0003)	.0000330 (.0013)
SECONDARY 1	.0000025 (.0001)	.0000050 (.0002)	.0000025 (.0001)
2	.0000127 (.0005)	0	.0000482 (.0019)
3	.0000152 (.0006)	.0000076 (.0003)	.0000177 (.0007)

TURBINE END SEAL WEAR PRETEST 116 TO POST TEST 158-m (IN.)			
POSITION	INLET	OUTLET	PAD
PRIMARY 1	.0000076 (.0003)	.0000101 (.0004)	0
2	.0000355 (.0014)	.0000203 (.0008)	.0000050 (.0002)
3	.0000203 (.0008)	.0000172 (.0006)	-.0000101 (-.0004)
SECONDARY 1	.0001651 (.0065)	.0001752 (.0069)	.0000685 (.0027)
2	.0001295 (.0051)	.0000762 (.0030)	.0003022 (.0119)
3	.0002717 (.0107)	.0002463 (.0097)	.0001955 (.0077)

The surface profile traces (Fig. 85 through 88) of the tapered carbon seal ring inside diameters indicate the following wear from pretest 116 to posttest 158:

	PUMP END	TURBINE END
PRIMARY	NONE	NONE
SECONDARY	.0000635m (.00025 in.)	.0000127 (.0005 in.)

The surface profile traces of the shaft mating ring sleeve at the seal contact locations indicated no significant wear, except for the turbine end secondary seal which was worn .0000381 to .0000762m (.00015 to .00030 in.), (Fig. 89 and 90).

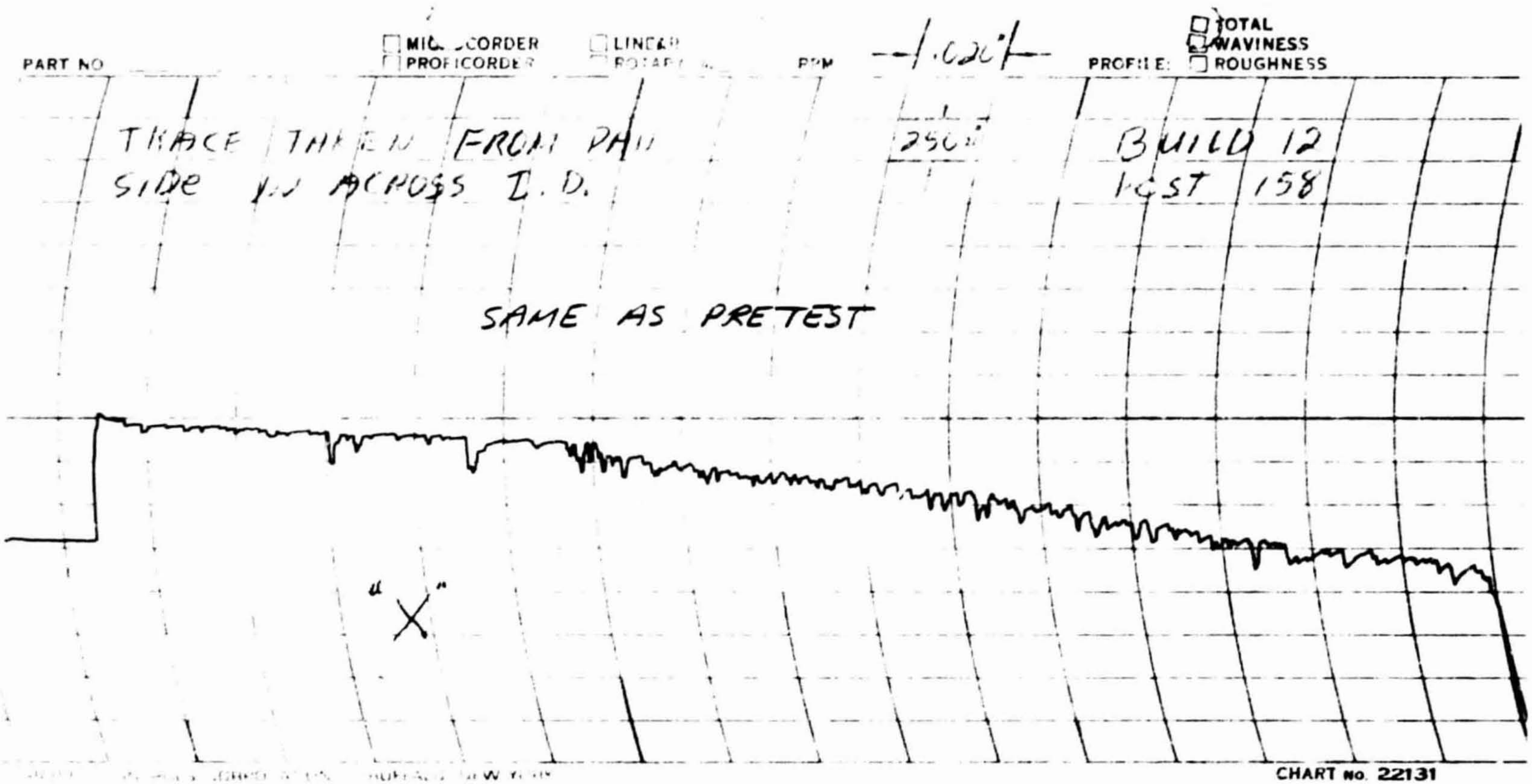


Figure 85. Surface Profile Trace Pump End, Primary Seal Ring,
P/N 7R0011525, S/N 047906, Build 12, Posttest 158

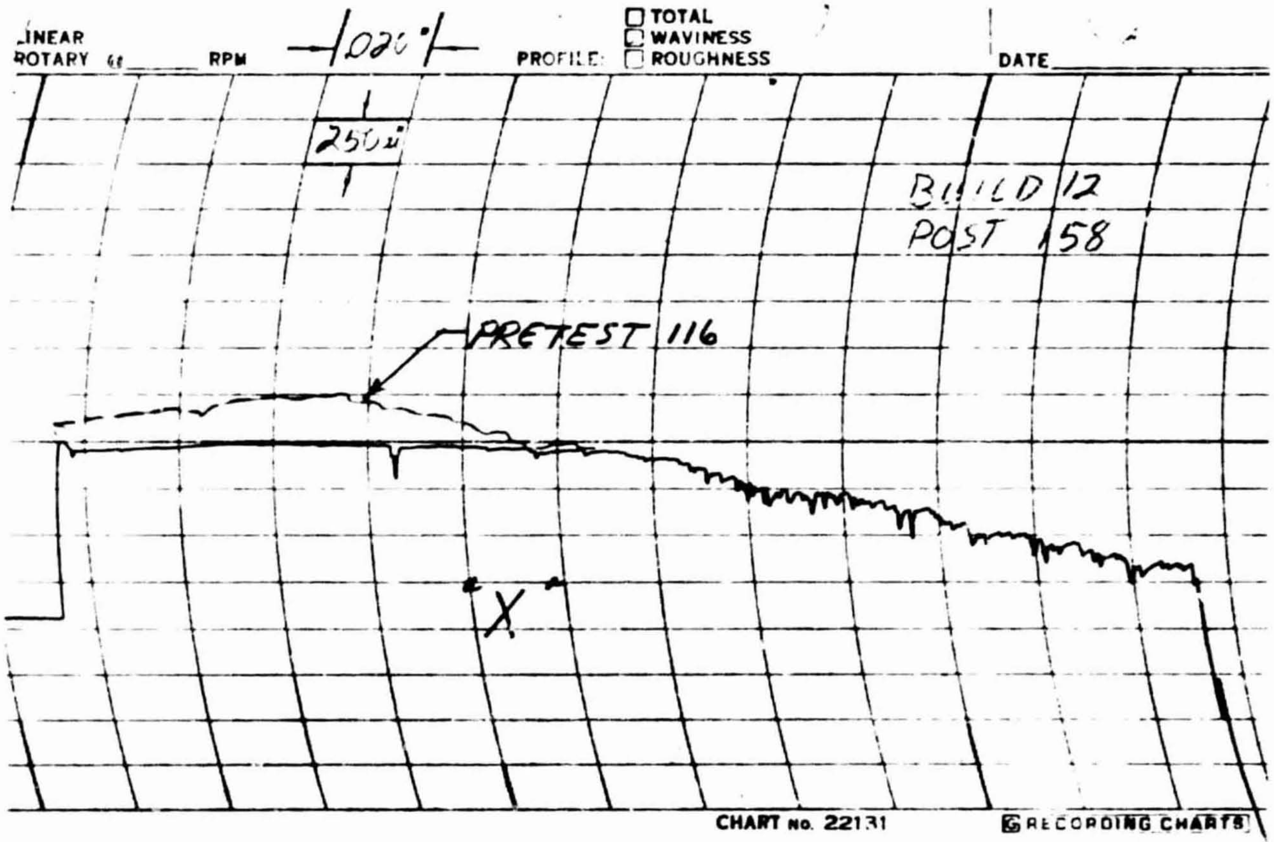


Figure 86. Surface Profile Trace Pump End, Secondary Seal Ring, P/N 7R0011526, S/N 047902, Build 12, Posttest 158

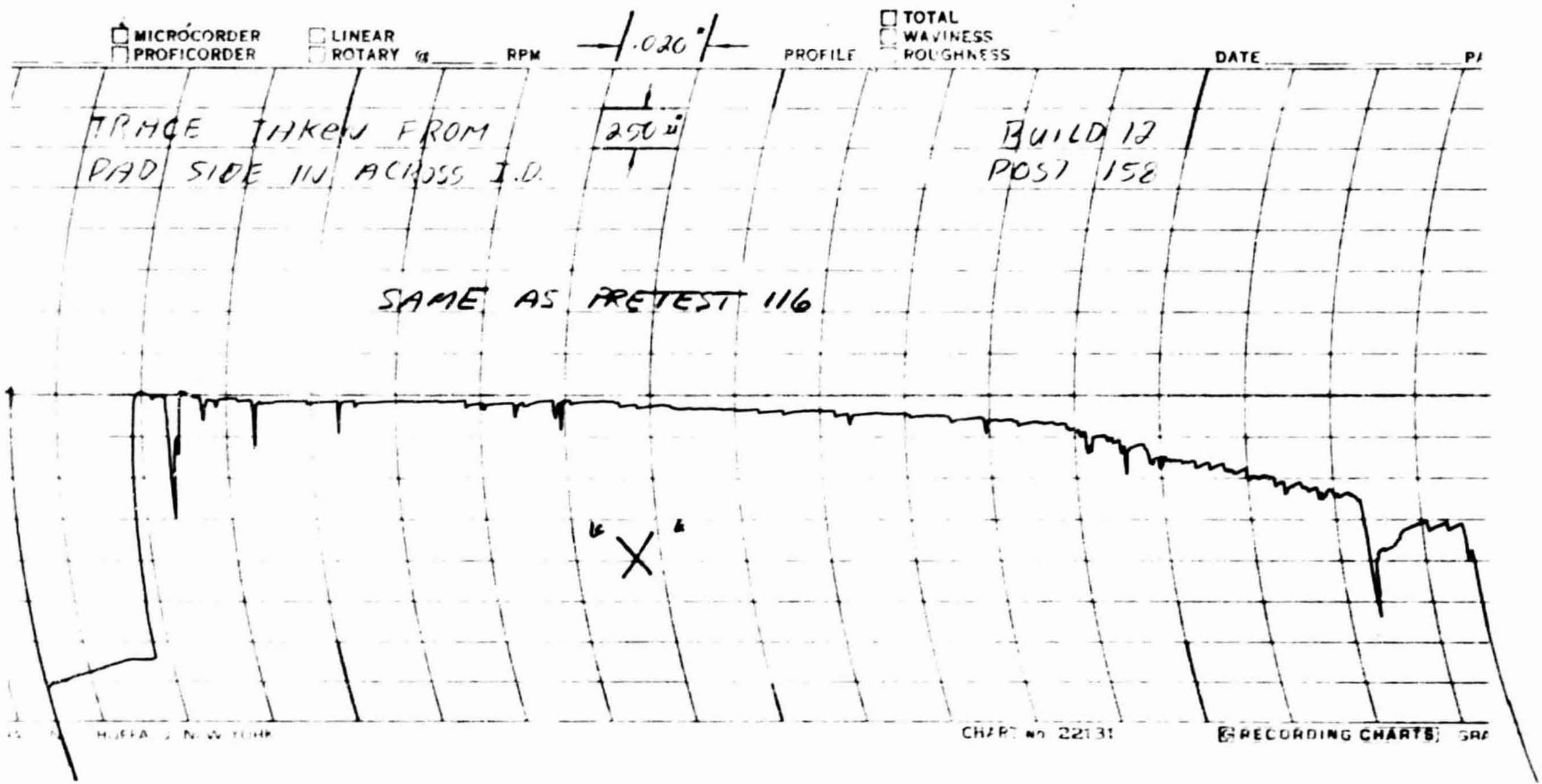


Figure 87. Surface Profile Trace Turbine End, Primary Seal Ring, P/N 7R0011525, S/N 047901, Build 12, Posttest 158

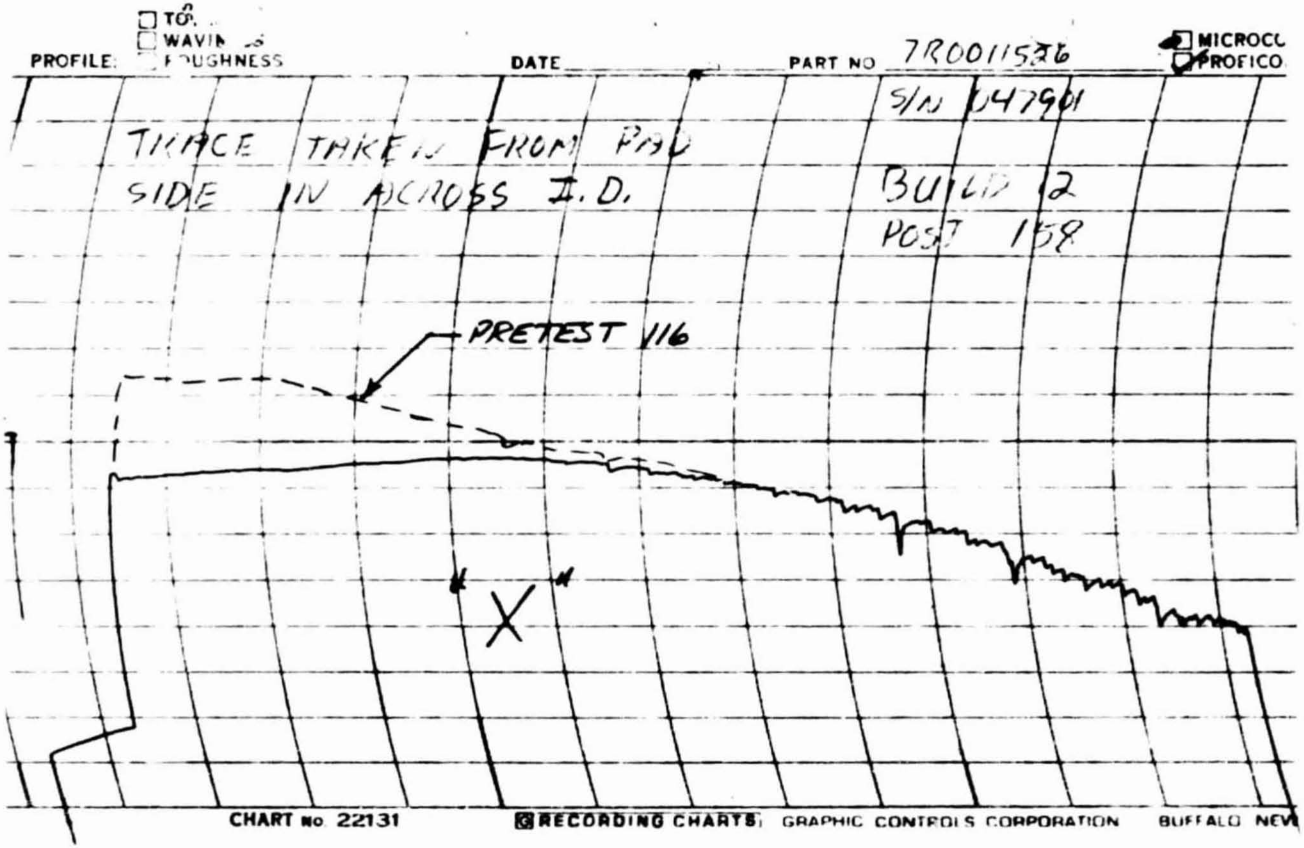
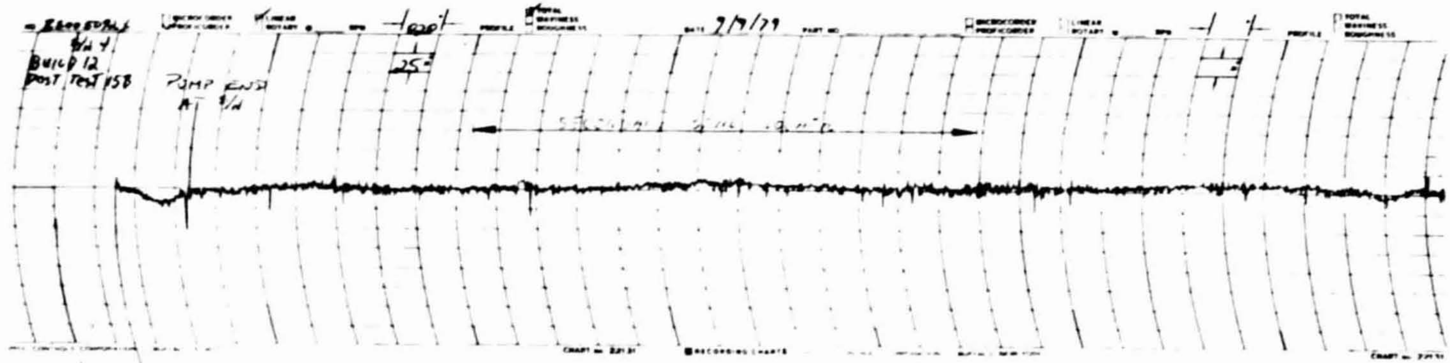
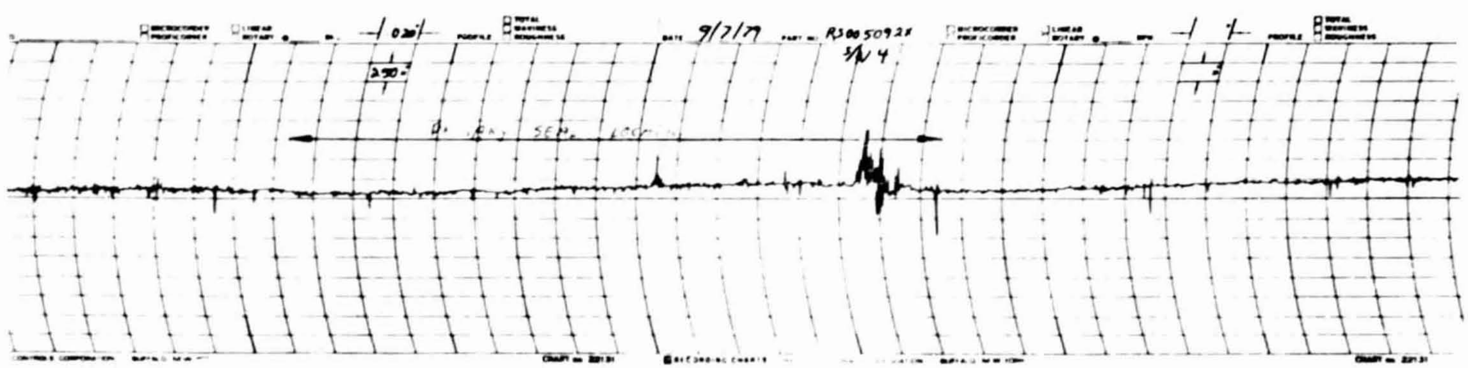


Figure 88. Surface Profile Trace Turbine End, Secondary Seal Ring, P/N 7R0011526, S/N 047901, Build 12, Posttest 158

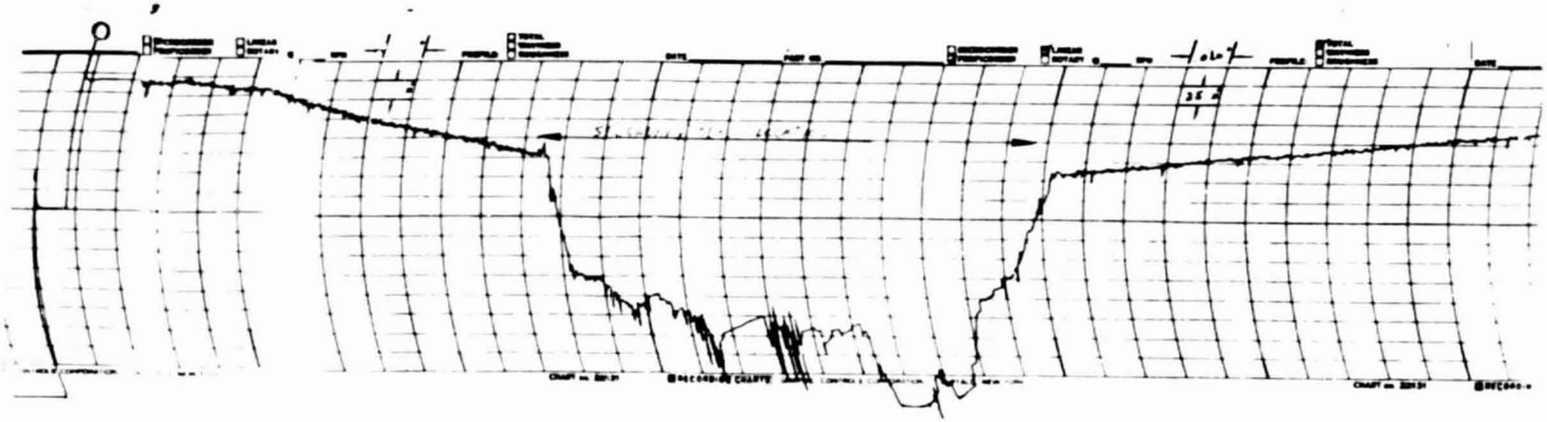


PUMP END SECONDARY SEAL LOCATION

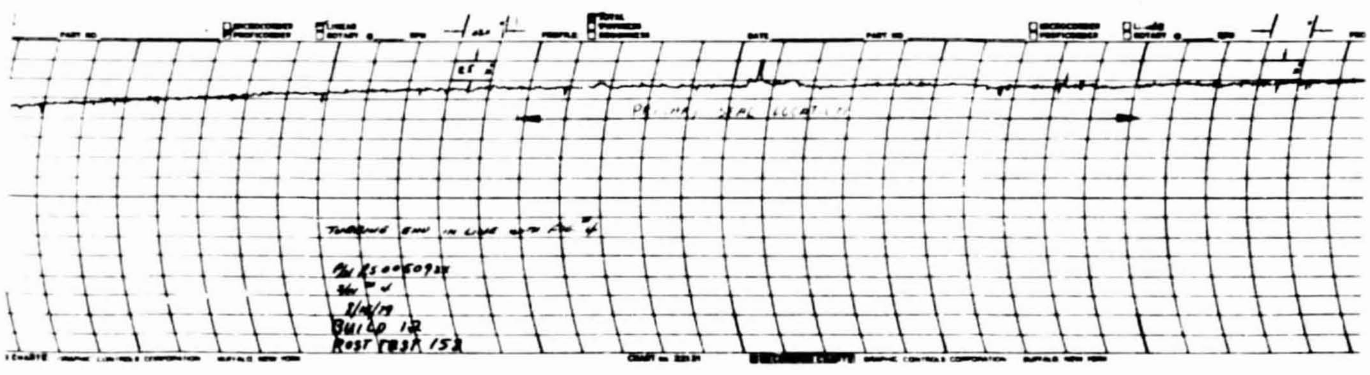


PUMP END PRIMARY SEAL LOCATION

Figure 89. Surface Profile Traces of Tester Mating Ring, Sleeve Pump End, P/N RS005092X, S/N 4, Build 12, Posttest 158



TURBINE END SECONDARY SEAL LOCATION



TURBINE END PRIMARY SEAL LOCATION

Figure 90. Surface Profile Traces of Tester Mating Ring Sleeve Turbine End, P/N RS005092X, S/N 4, Build 12, Posttest 158

Build 13 Assembly Pretest 159

The tester was reassembled with the new tapered bore rings using the same housings as Build 12. A new shaft sleeve mating ring was installed. The seal ring to shaft sleeve diametral clearances at assembly are given below:

	PUMP END SEAL-m (IN.)		TURBINE END SEAL-m (IN.)	
	INLET	OUTLET	INLET	OUTLET
PRIMARY	.000241 (.0095)	.0002413 (.0095)	.0000289 (.0114)	.0002489 (.0098)
SECONDARY	.000220 (.0087)	.0001701 (.0067)	.0002413 (.0095)	.0001955 (.0077)

Tests 159 through 218

The pretest static leakage using ambient temperature gasous nitrogen was measured at 3447378 n/m^2 (500 psi) pressure increments from 3447378 to 19305320 n/m^2 (500 to 2800 psig). The leakage varied from .1723 kg/sec (.38 lb/sec) at 3447378 n/m^2 (500 psig) to .8536 kg/sec (1.882 lb/sec) at 19305320 n/m^2 (2800 psig). The results are given in Table 12.

The hot gaseous nitrogen acceleration test series was resumed with a new set of tapered bore carbon seal rings. The shaft speed was ramped to 3036 rad/sec (29000 rpm) in 10 seconds or less. The seal pressure was increased from 344737 to 24131650 n/m^2 (50 to 3500 psig) during the same period. The hot gas temperature was 533K (500 F) at start and gradually decayed to approximately 366K (200 F) at cutoff. A total of 60 tests for 150 minutes was performed to complete the test objective. The results are given in Table 12.

The seal performance was satisfactory with measured total leakage rates of .5896 to .6803 kg/sec (1.3 to 1.5 lb/sec) on the pump end seal and .6803 to .7257 kg/sec (1.5 to 1.6 lb/sec) from start of test through 150 minutes of accumulated test time. The turbine end seal total leakage shows a gradual incr[illegible]m .7257 to .7711 kg/sec (1.6 to 1.7 lb/sec) at start to .8164 to .861[illegible] (1.8 to 1.9 lb/sec) at 150 minutes. The leakage data indicate no signifi[illegible] wear on the pump end seal and gradual wearing of the turbine end seal.

The seal drain pressure data versus test time show constant drain pressures on the pump end primary and secondary seal drains. The turbine end seal showed constant primary drain pressure and gradually increasing secondary drain pressure. The drain pressure data indicate no significant wear on the pump end primary seal, the pump secondary seal, and the turbine end primary seal. The data indicate gradual wearing of the turbine end secondary seal.

Build 13 Disassembly Posttest 218

The scheduled inspection after 2.5 hours accumulated test time revealed the seals to be in good condition with negligible wear, except for the turbine end secondary seal. The axial sealing dam and bearing pad was worn .000312 to .000391m (.0123 to .0154) in.). The carbon bore was worn 0 to .000149m (.0059 in.) diametral on the inlet and 0 to .0001905 m (.0075 in.) diametral on the outlet. The carbon was chipped around the outlet edge. The inspection summary is given in Table 10. The measured wear from Pretest 159 to posttest 218 is given below: (negative wear is a result of measurement tolerances)

PUMP END SEAL WEAR-m (IN.) (TESTS 159 TO 218)			
POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	.0000279 (.0011)	0	-.0000254 (-.0001)
2	0	.0000431 (.0017)	-.0000101 (-.0004)
3	.0000254 (.0010)	.0000457 (.0018)	.0000076 (.0003)
SECONDARY 1	-.0000101 (-.0004)	.0000050 (.0002)	.0000558 (.0022)
2	.0000177 (.0007)	.0000330 (.0013)	.0000346 (.0053)
3	.0000177 (.0007)	.0000304 (.0012)	.0001397 (.0055)

TURBINE END SEAL WEAR-m (IN.) (TESTS 159 TO 218)			
POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	.0000177 (.0007)	.0000482 (.0019)	.0000025 (.0001)
2	.0000127 (.0005)	.0000304 (.0012)	.0000101 (-.0004)
3	.0000025 (.0001)	.0000330 (.0013)	-.0000101 (-.0004)
SECONDARY 1	.0001041 (.0041)	.0001295 (.0051)	.0003911 (.0154)
2	.0001498 (.0059)	.0001905 (.0075)	.0003403 (.0134)
3	-.0000711 (-.0028)	-.0000279 (-.0011)	.0003124 (.0123)

The surface profile traces of the tapered carbon seal ring inside diameters indicate the following radial wear from pretest 159 to posttest 218:

POSITION		PUMP END-m (IN.)	TURBINE END-m (IN.)
PRIMARY	1	.0000050 (.00020)	.000023875 (.000094)
	2	.0000048 (.00019)	.000010414 (.00041)
	3	.0000076 (.00030)	.000009144 (.00036)
SECONDARY	1	.0000099 (.00039)	.00002286 (.00090)
	2	.0000096 (.00038)	.000013208 (.00052)
	3	.0000060 (.00024)	.00001524 (.00060)

The surface profile traces of the shaft mating ring sleeve at the seal contact locations indicate no significant wear, except for the turbine end secondary seal which was worn .0000030 m (.00012 in.).

The tester bearings with the special silver-plated 4130 cages were in good condition.

At that point, it was determined that the gradual increase of the turbine end seal leakage was imposing high thrust conditions on the bearings and that a new bearing arrangement would be needed to prevent possible seal damage. The modified bearings arrangement was designed to absorb a greater thrust load on the shaft caused by the increased pressure in the turbine end secondary seal drain cavity.

Build 14 Assembly Pretest 219

The tester was reassembled with the same seal hardware as Build 13. The seal ring to shaft sleeve diametral clearances at assembly are given below:

BUILD 14 PRETEST 219 DIAMETRAL CLEARANCE-m (IN.)				
	PUMP END SEAL		TURBINE END SEAL	
	INLET	OUTLET	INLET	OUTLET
PRIMARY	.0002667 (.0105)	.0002387 (.0094)	.0003098 (.0122)	.0002997 (.00118)
SECONDARY	.0002083 (.0082)	.0001727 (.0068)	.0003479 (.0137)	.0003276 (.0129)

Tests 219 through 278

The pretest static leakage using ambient temperature gaseous nitrogen was measured at 3447378 n/m^2 (500 psi) pressure increments from 3447378 to 15168465 n/m^2 (500 to 2200 psig). The leakage varied from .1669 to .74162 kg/sec (.368 to 1.635 lb/sec) on the pump end seal and from .2494 to 1.2891 kg/sec (.55 to 2.842 lb/sec) on the turbine end seal. The results are given in Table 12.

The seal performance was satisfactory with measured total leakage rates of .6803 to .7257 kg/sec (1.5 to 1.6 lb/sec) on the pump end seal and .7711 to .861 kg/sec (1.7 to 1.9 lb/sec) on the turbine end seal (Table 12). The pump end seal leakage was nearly constant during the test series. The turbine end seal leakage generally shows an increasing trend. The leakage data indicate no significant wear on the pump end seal and gradual wearing of the turbine end seal.

The pump end seal primary and secondary drain cavity pressures were essentially constant during the test series (Table 12). The turbine end seal primary drain pressure generally decreased and the secondary drain pressure increased, indicating no significant wear on the primary seal and excessive wear on the secondary seal.

Build 14 Disassembly Posttest 278

The scheduled inspection after an additional 2.5 hours and total of 5.0 hours test time revealed the seals to be in satisfactory condition with negligible wear, except for the turbine end secondary seal. The axial sealing dam and bearing pad was worn completely off at one location. The axial wear was .0000228 to .0001219 m (.0009 to .0048 in.) on this build and .000414 to .0006908 m (.0163 to .0272 in.) total, indicating that most of the axial wear occurred during the first 2.5 hours. The axial wear apparently stopped after the dam and bearing pad was worn off, resulting in full contact on the axial surface of the seal ring. There was evidence of contact between the axial surface of the metal retainer band and the seal housing.

The turbine end secondary seal carbon bore was worn .000762 to .001036 m (.0300 to .0408 in.) diametral on the inlet and .0007874 to .0010718 m (.0310 to .0422 in.) diametral on the outlet during Build 14. The total bore wear is .0008864 to .0009652 m (.0249 to .0380 in.) diametral on the inlet and .00955 to .001044 m (.0376 to .0411 in.) diametral on the outlet, indicating that most of the bore wear occurred during this build.

The bore wear apparently increased excessively after the axial dam was [illegible] due to the greater unbalanced axial pressure force which increased the radial friction force and results in excessive rubbing at the bore. Seal bore rubbing occurs when the radial friction and inertia forces exceed the hydrostatic centering force.

The pump end secondary seal axial dam and bearing pad was worn .0000609 to .000154 m (.0024 to .0061 in.) on this build and .0001168 to .0002895 m (.0046 to .0114 in.) total. There was no bore wear.

The inspection summary is given in Table 10. The hardware summary is given in Table 7 . The seal wear on Build 14 and the total wear is given below: (negative wear is a result of measurement tolerances)

PUMP END SEAL BUILD 14 WEAR-m (IN.) (TESTS 219-278)				
POSITION		INLET DIA.	OUTLET DIA.	PAD
PRIMARY	1	.0000254 (-.0010)	.0000152 (.0006)	-.0000050 (-.0002)
	2	.0000101 (-.0004)	-.0000025 (-.0001)	.0000050 (.0002)
	3	.0000254 (-.0001)	0 0	-.0000101 (-.0004)
SECONDARY	1	.0000177 (-.0007)	-.0000254 (-.0010)	.0000609 (.0024)
	2	0 0	-.0000050 (-.0002)	.0001549 (.0061)
	3	.0000025 (.0001)	-.0000152 (-.0006)	.0001143 (.0045)

TURBINE END SEAL BUILD 14 WEAR (TESTS 219 THROUGH 278)-m (IN.)			
POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	.0000254 (.0010)	.0000050 (.0002)	.0000101 (.0004)
2	.0000076 (.0003)	.0000025 (.0001)	.0000127 (.0005)
3	.0000152 (.0006)	.0000025 (.0001)	.0000076 (.0003)
SECONDARY 1	.0007823 (.0308)	.0008255 (.0325)	.0000228 (.0009)
2	.000762 (.0300)	.0007874 (.0310)	.0001066 (.0042)
3	.0010363 (.0408)	.0010718 (.0422)	.0001219 (.0048)

PUMP END SEAL TOTAL WEAR(TEST 159 THROUGH 278) m (IN.)			
POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	.0000025 (.0001)	.0000152 (.0006)	-.0000076 (-.0003)
2	-.0000101 (-.00004)	.0000406 (.0016)	-.0000050 (-.0002)
3	.0000228 (.0009)	.0000304 (.0012)	-.0000025 (-.0001)
SECONDARY 1	-.0000279 (-.0011)	-.0000203 (-.0008)	.0001168 (.0046)
2	.0000177 (.0007)	.0000279 (.0011)	.0002895 (.0114)
3	.0000203 (.0008)	.0000152 (.0006)	.000254 (.0100)

TURBINE END SEAL TOTAL WEAR (TESTS 159 THROUGH 278)-m (IN.)			
POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	.0000431 (.0017)	.0000533 (.0021)	.0000127 (.0005)
2	.0000203 (.0008)	.0000330 (.0013)	.0000025 (.0001)
3	.0000177 (.0007)	.0000355 (.0014)	.0000025 (.0001)
SECONDARY 1	.0008864 (.0349)	.0009550 (.0376)	.0004140 (.0163)
2	.0009118 (.0359)	.0009779 (.0385)	.0004470 (.0176)
3	.0009652 (.0380)	.001044 (.0411)	.0004343 (.0171)

The surface profile traces of the tapered carbon seal ring inside diameters indicate negligible wear on the pump end seal rings. The turbine end primary seal ring trace indicates a diverging taper with .0000317 m (.00125 in.) radial wear on this build and .0000635 m (.0025 in.) total radial wear. The turbine end secondary seal ring trace indicates a diverging taper with heavy wear at the

C-3

exit. The amount of wear cannot be determined because the reference diameter at the inlet is worn. The wear indicated by the profile traces is given below:

CARBON BORE PROFILE TRACE WEAR (TESTS 219 THROUGH 278)-m (IN.)		
POSITION	PUMP END	TURBINE END
PRIMARY 1	NONE	.0000317 (.00125)
2	NONE	.0000154 (.00061)
3	NONE	.0000063 (.00025)
SECONDARY 1	NONE	.0000086 (.00034)
2	NONE	.0000093 (.0037)
3	NONE	.0000048 (.00019)

The surface profile traces of the shaft mating ring sleeve at the seal contact locations indicate no significant wear, except for the turbine end secondary seal which was worn an additional .00003302 m (.0013 in.) during this build and .00003556 m (.0014 in.) total.

Build 15 Assembly Pretest 279

The tester was reassembled with the same seal hardware as Build 14. The seal ring to shaft diametral clearances at assembly are given below:

	PUMP END SEAL-m (IN.)		TURBINE END SEAL-m (IN.)	
	INLET	OUTLET	INLET	OUTLET
PRIMARY	.0002489 (.0098)	.0002616 (.0103)	.0003378 (.0133)	.000307 (.0121)
SECONDARY	.0001981 (.0078)	.0001549 (.0061)	.0011328 (.0446)	.0011557 (.0455)

Tests 279 though 297

The hot gaseous nitrogen acceleration test series was resumed with the same seal hardware as Build 14. The shaft speed was ramped to 3036.88 rad/sec (29,000 rpm) in 10 seconds or less. The seal pressure was increased from 344737.86 to 24131650.2 n/m^2 (50 to 3500 psig) during the same period. The hot gas temperature was 533.15K (500 F) at start and gradually decayed to approximately 338.7K (150 F) at cutoff. A total of 19 test for 47.5 minutes was performed to complete the test objective of 7.5 hours. The results are given in Table 12.

The seal performance was satisfactory with measured total leakage rates of .63503 to .72574 kg/sec (1.4 to 1.6 lb/sec) on the pump end seal and .7711 to

.95254 kg/sec (1.7 to 2.1 lb/sec) on the turbine end seal (Table 12). The leakage rates adjusted to 24131640.2 n/m^2 (3500 psig) inlet pressure (Fig. 91) show nearly constant total leakage for the pump end seal from start of test through 358 minutes of accumulated test time. The turbine end seal total leakage shows a gradual increase from .72574 to .7711 kg/sec (1.6 to 1.7 lb/sec) at start to .86182 to .909185 kg/sec (1.9 to 2.0 lb/sec) at 358 minutes. The leakage data indicate relatively little wear on the pump end seal and gradual wearing of the turbine end seal.

The seal drain pressure plots versus test time (Fig. 92) show nearly constant drain pressures on the pump end primary and secondary seal drains. The turbine end primary seal shows a decreasing drain pressure. The secondary seal drain pressure also shows a decrease. This decrease, however, is due to a different size nozzle placed on the drain outlet pipe. Once this different nozzle is accounted for the pressure was found to be gradually increasing. The drain pressure data indicate relatively little wear on the pump end primary seal, the pump end secondary seal and the turbine end secondary seal. Both seals maintained satisfactory drain pressures throughout the total accumulated test time.

Build 15 Disassembly Posttest 297

The scheduled inspection after 47.5 minutes or total of 7.5 hours revealed the seals to be in satisfactory condition. The pump end primary seal was in very good condition with little wear throughout the total accumulated test time. The pump end secondary seal axial sealing dam and bearing pad total wear was .0001371 to .0003327 m (.0054 to .0131 in.). The carbon bore showed negligible wear. Visual inspection of the pump end secondary seal showed some chipping on the downstream edge of the face at the carbon bore and contact pattern halfway across the bore on the downstream side.

The turbine end primary seal was in good condition with negligible wear. Visual inspection revealed a uniform rubbing contact pattern over 90% of the bore toward the downstream edge. The turbine end secondary seal was worn .0007035 to .0010134 m (.0277 to .0399 in.) diametral on the inlet and .0007848 to .0010566 m (.0309 to .0416 in.) diametral on the outlet. The axial sealing dam and bearing pad showed .0004038 to .0004673 m (.0159 to .0184 in.) wear. Visual inspection showed heavy rubbing contact across the bore and excessive chipping on the downstream edge of the bore. The bearing pads were completely worn off over one-third of the face and nearly all worn off over the remainder.

The fact that the turbine end seals consistently showed more wear than the pump end seals implies that the wear may be a result of shaft deflections which caused contact at the turbine end of the shaft sleeve. Supporting this is the fact that shaft sleeve total wear at the turbine end .0000385 m (.001518 in.), was far greater than at the pump end, .0000127 m (.0005 in.). The hardware condition is shown on Fig. 93 through 105. The inspection summary is given in

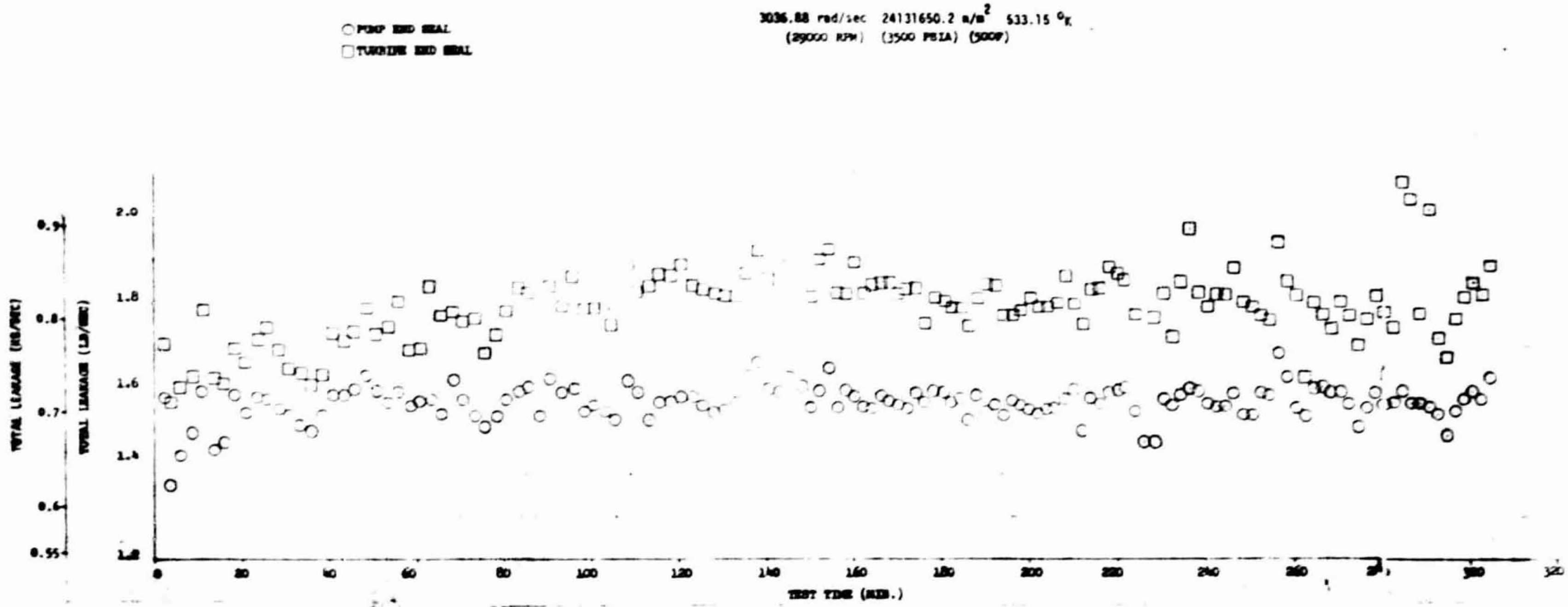


Figure 91. Tapered Bore Seal Total Leakage vs Test Time Tests 159-297

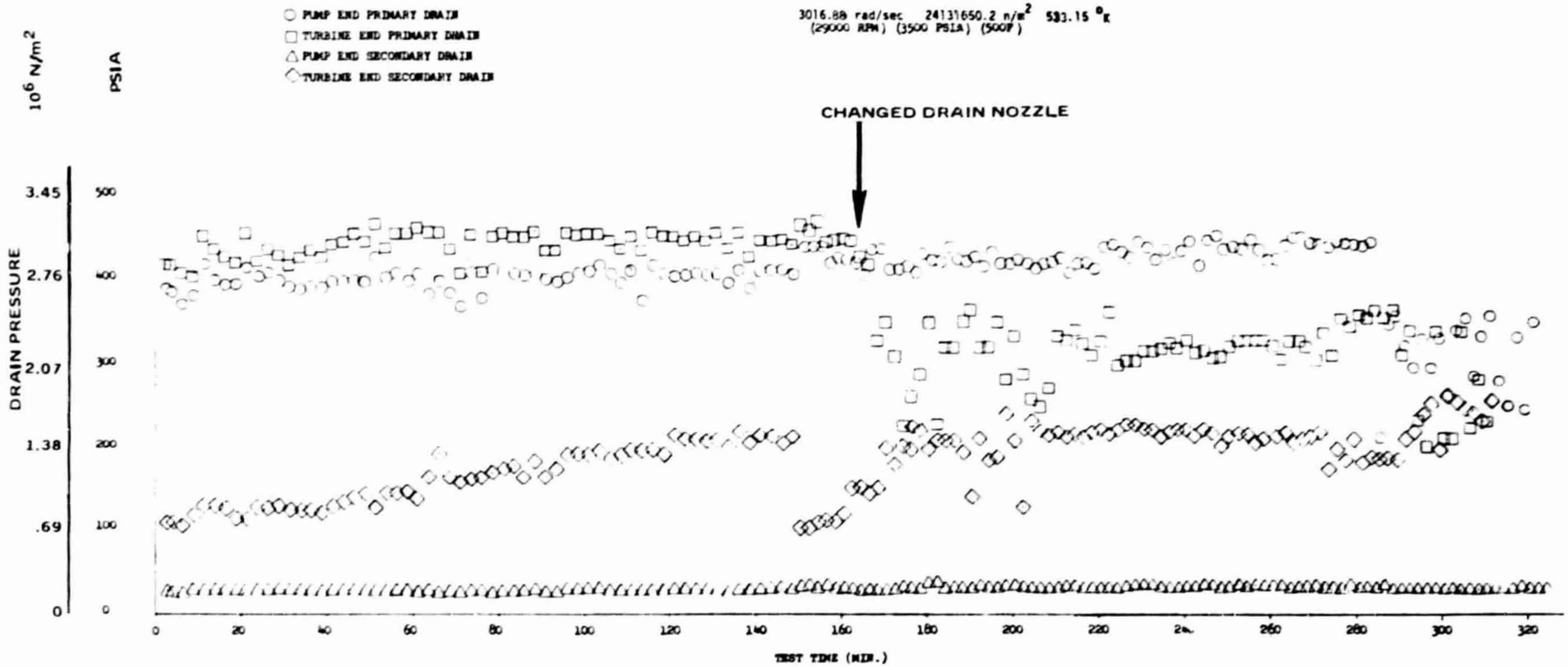


Figure 92. Tapered Bore Seal Drain Pressure vs Test Time, Tests 159-297

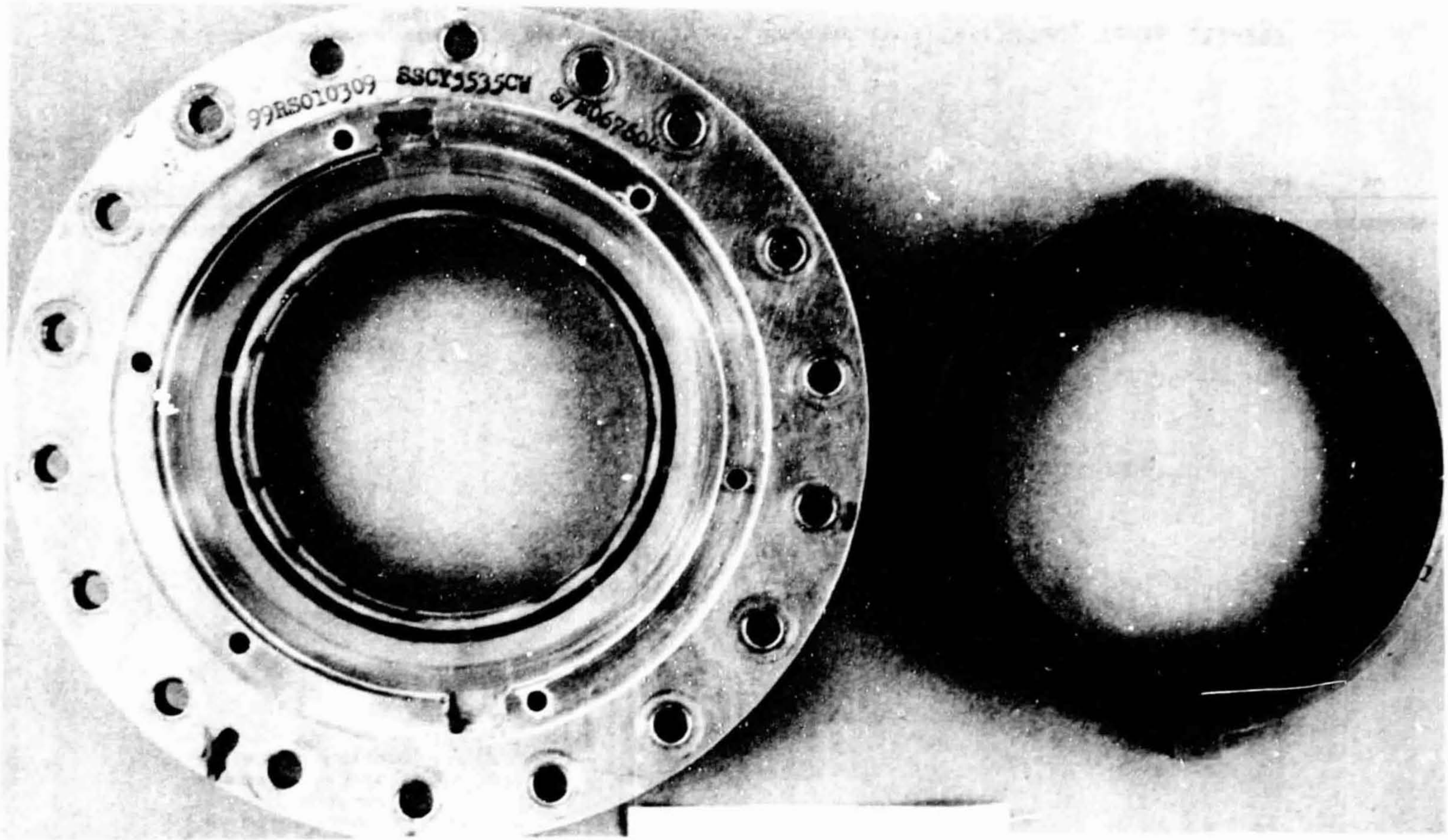


Figure 93. Pump End Primary Seal, P/N 7R0011525, S/N 047909, Build 15, Posttest 297

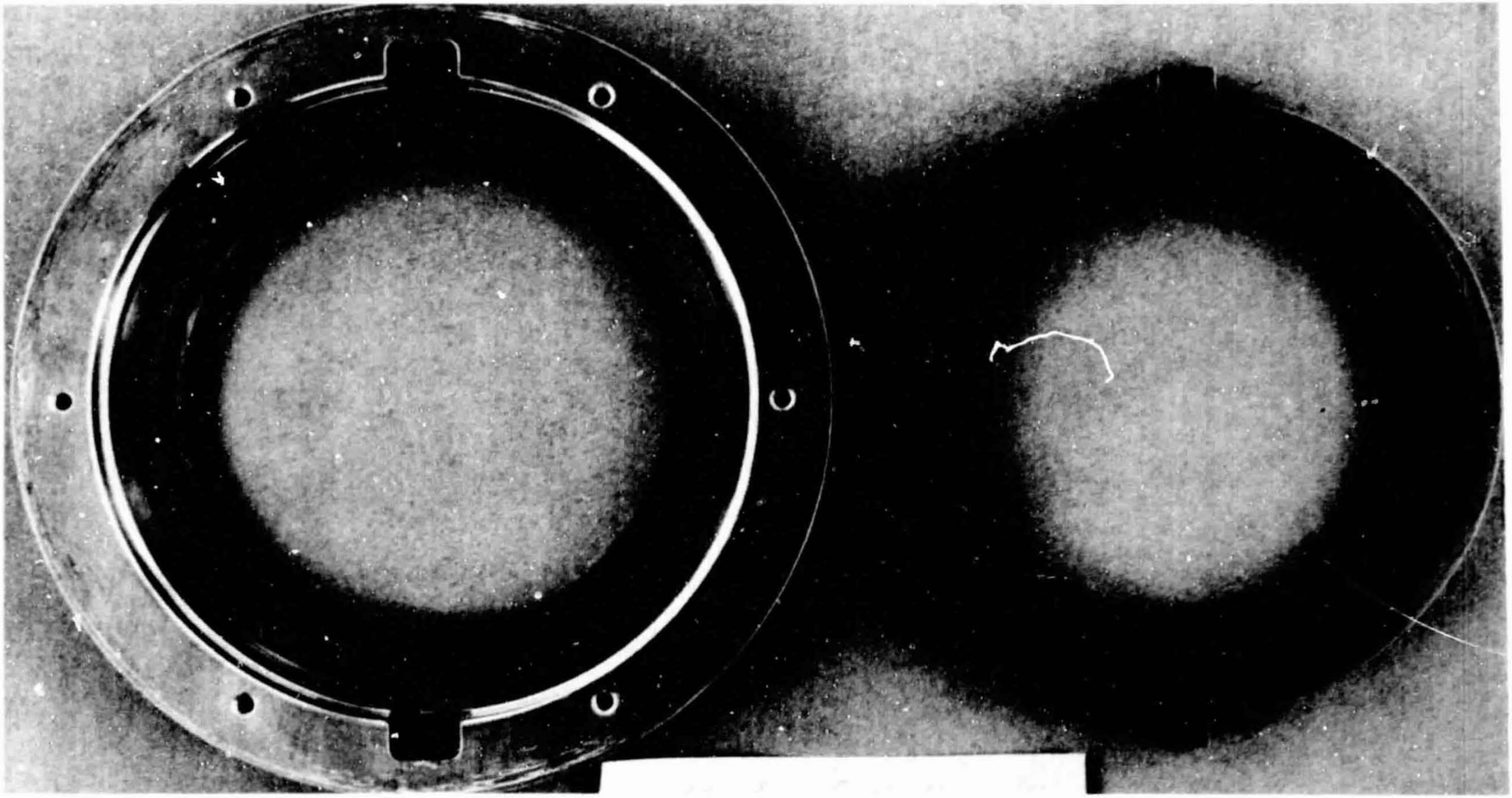


Figure 94. Pump End Secondary Seal, P/N 7R0011526, S/N 047909, Build 15, Posttest 297

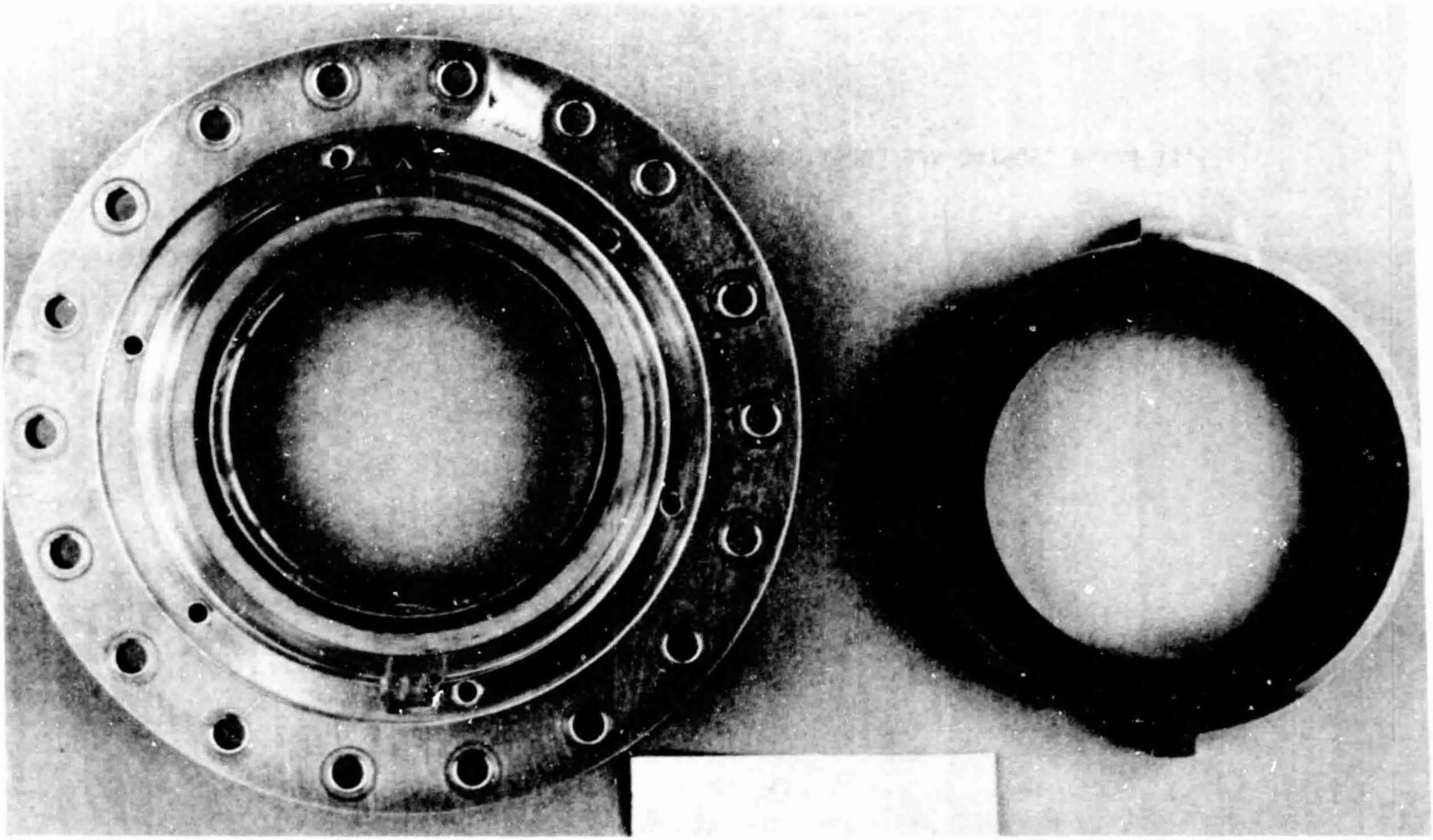


Figure 95. Turbine End Primary Seal, P/N 7R0011525, S/N 047907, Build 15, Posttest 297

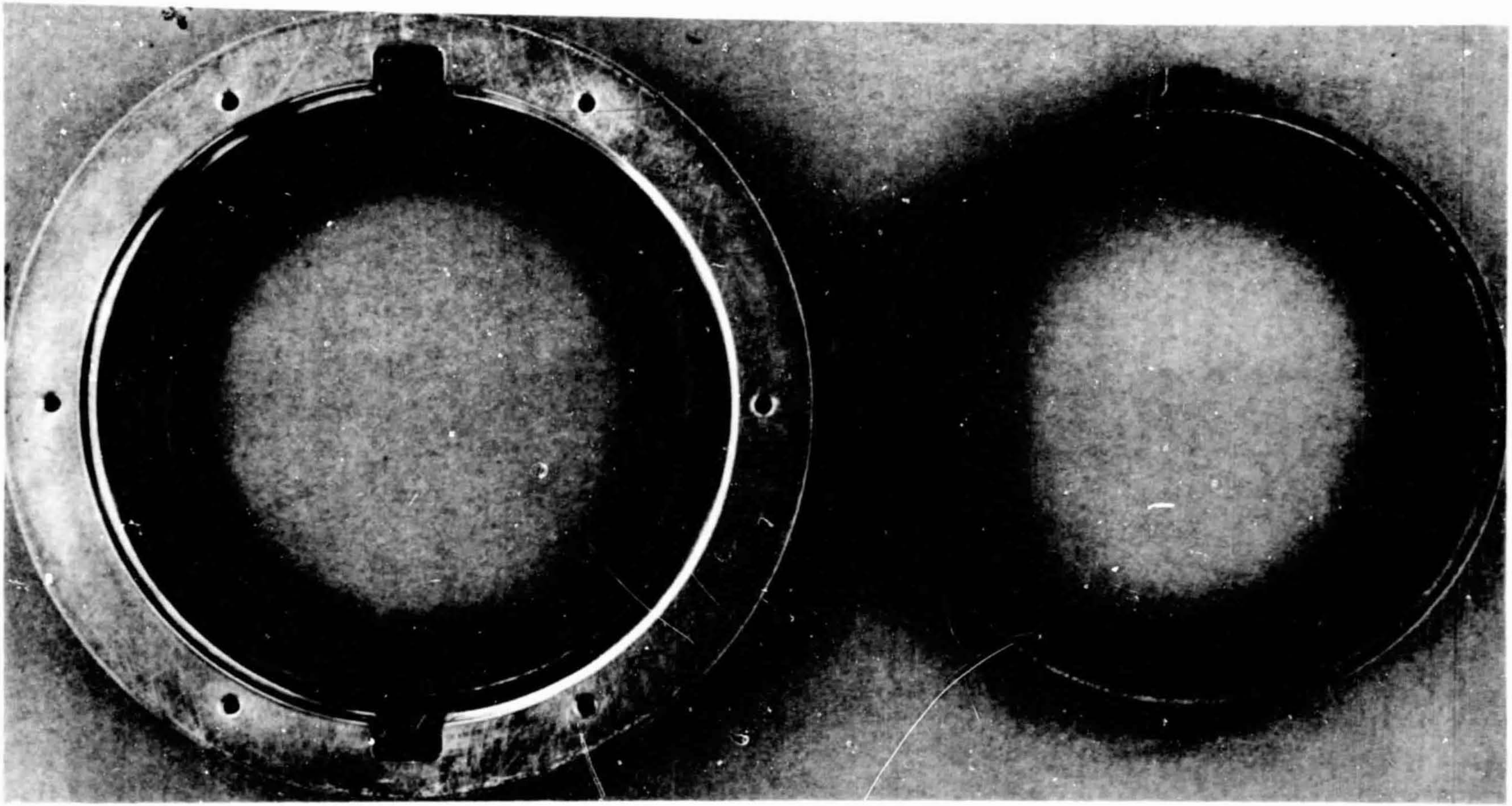


Figure 96. Turbine End Secondary Seal, P/N 7R0011526, S/N 047907, Build 15, Posttest 297

Figure 97. Pump End Primary Seal Ring (Position 1), P/N 7R0011525, S/N 047909, Build 15, Posttest 297

Figure 98. Pump End Primary Seal Ring (Position 2), P/N 7R0011525, S/N 047909, Build 15, Posttest 297

Figure 99. Pump End Secondary Seal Ring (Position 1), P/N 7R0011526, S/N 047909, Build 1:, Posttest 297

Figure 100. Pump End Secondary Seal Ring (Position 2), P/N 7R0011526, S/N 047909, Build 15, Posttest 297

Figure 101. Turbine End Primary Seal Ring (Position 1), P/N 7R0011525, S/N 047909, Build 15, Posttest 297

Figure 102. Turbine End Primary Seal Ring (Position 2), P/N 7R0011525, S/N 047907, Build 15, Posttest 297

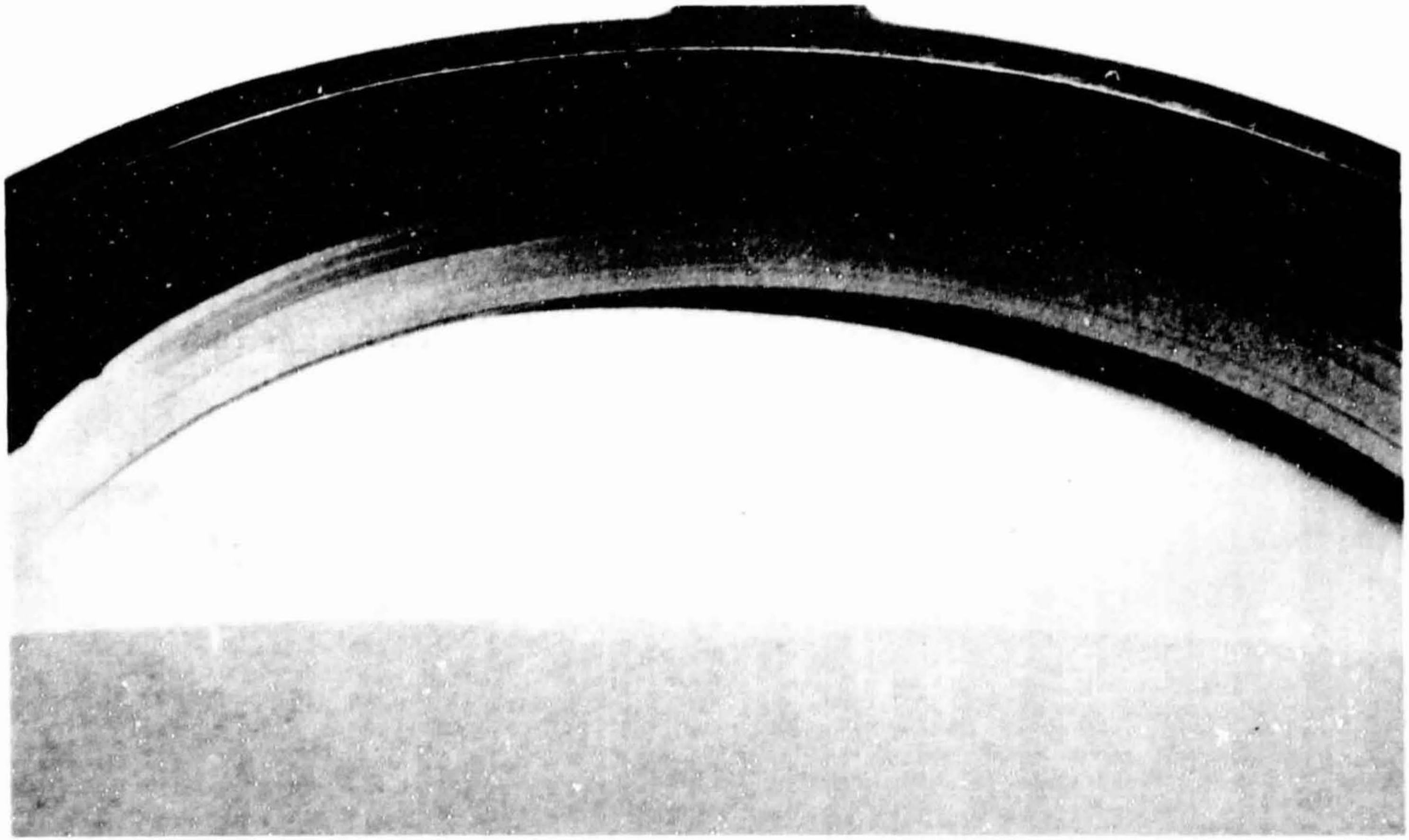


Figure 103. Turbine End Secondary Seal Ring (Position 1), P/N 7R00011526, S/N, 047907, Build 15, Posttest 297

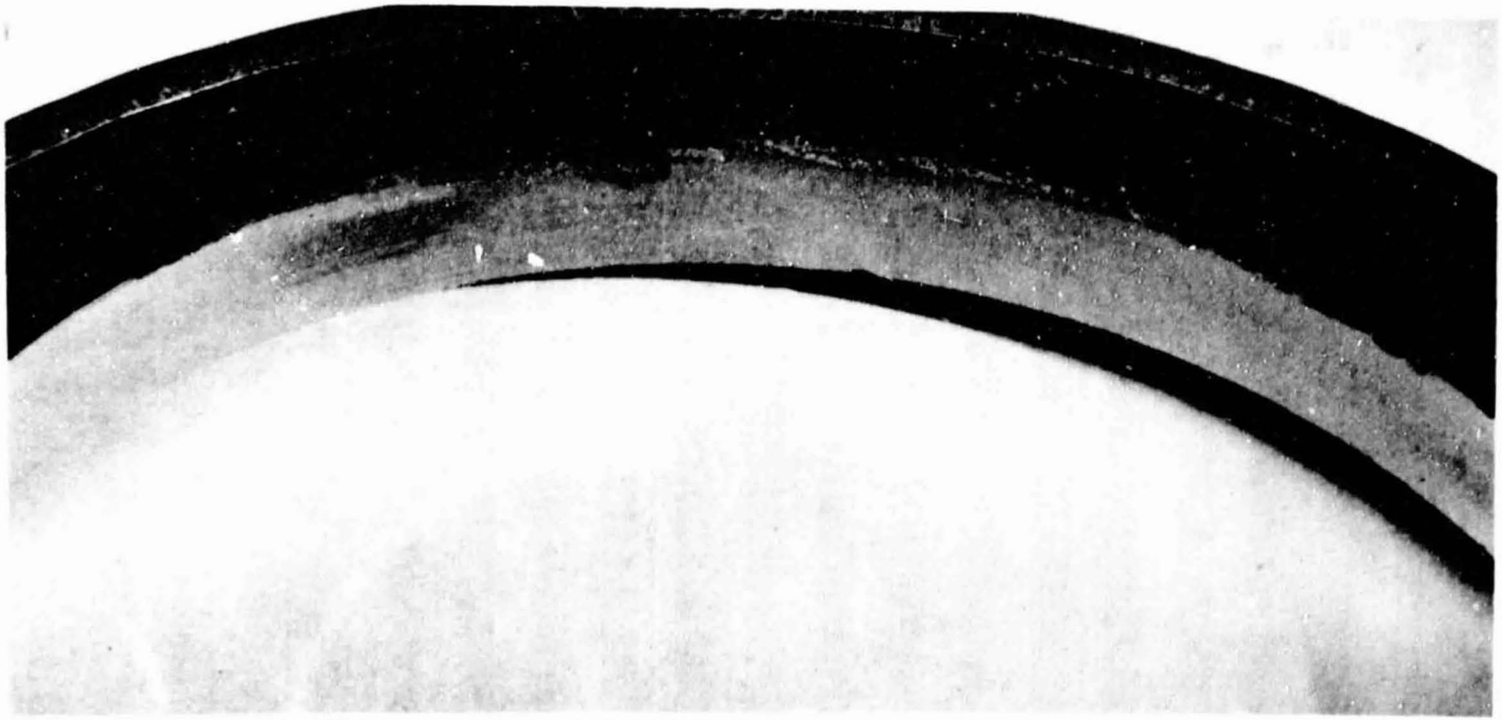
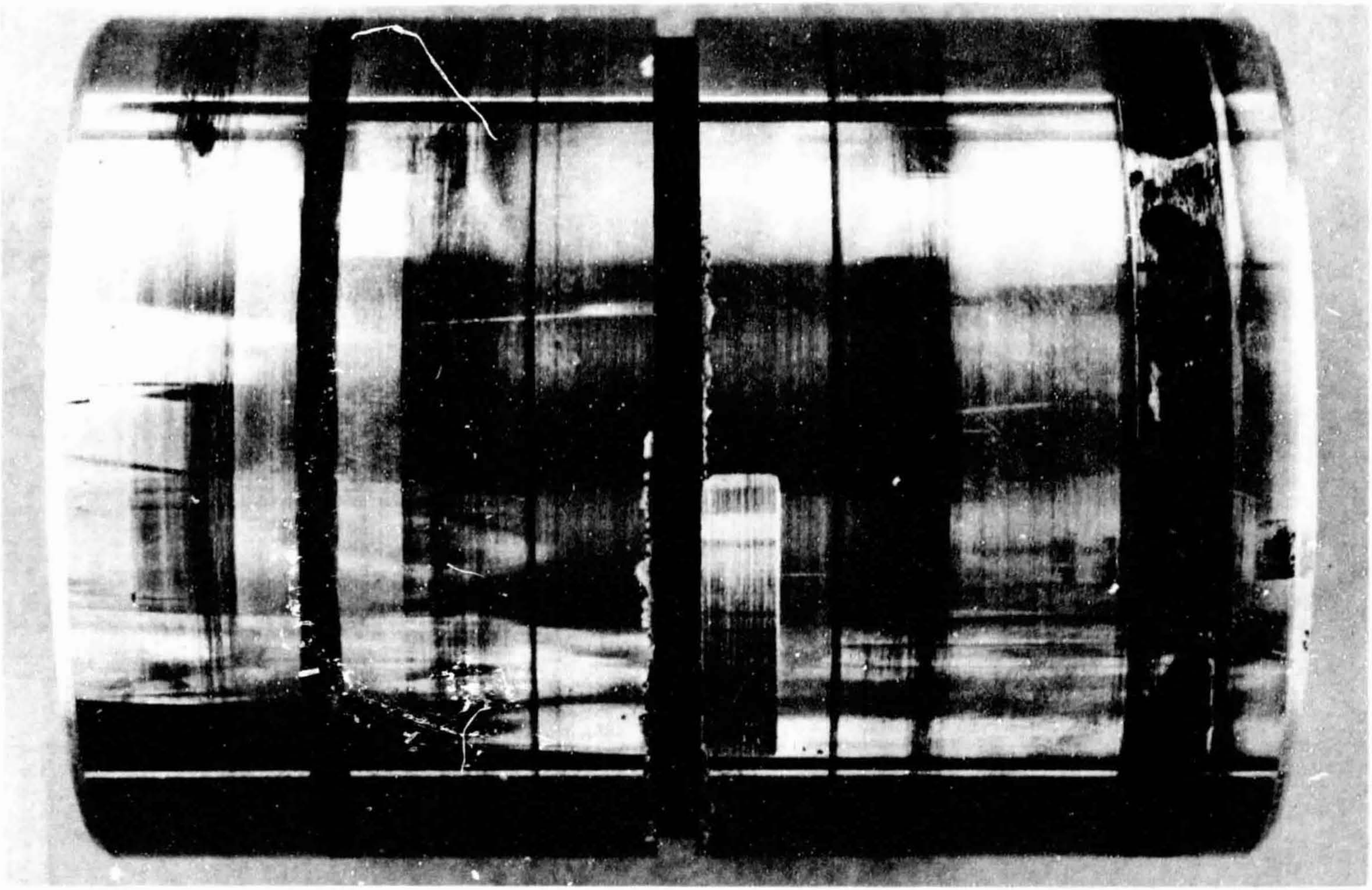


Figure 104. Turbine End Secondary Seal Ring (Position 2), P/N 7R00011526, S/N, 047907, Build 15, Posttest 297



PUMP END TURBINE END

Figure 105. Mating Ring Sleeve, P/N RS005092X-005, S/N 1, Build 15, Posttest 297

Table 10. The measured total wear from pretest 159 to post test 297 is given below: (negative wear is a result of measurement tolerances)

PUMP END SEAL TOTAL WEAR (TESTS 159 THROUGH 297)-m (IN.)			
POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	.0000300 (.0013)	.0000040 (.0002)	-.0000076 (-.0003)
2	.0000330 (-.0013)	.0000025 (.0001)	-.0000177 (-.0007)
3	.0000152 (.0006)	.0000381 (.0015)	-.0000050 (-.0002)
SECONDARY 1	-.0000558 (-.0022)	.0000101 (.0004)	.0001371 (.0054)
2	.0000025 (.0001)	.0000330 (.0013)	.0003327 (.0131)
3	.0000127 (.0005)	.0000127 (.0005)	.0002286 (.0090)

TURBINE END SEAL TOTAL WEAR (TESTS 159 THROUGH 297)-m (IN.)			
POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	.0000050 (.0002)	.0000300 (.0013)	.0000127 (.0005)
2	.0000050 (.0002)	.0000228 (.0009)	.0000076 (.0003)
3	.0000101 (-.0004)	.0000254 (.0010)	-.0000025 (-.0001)
SECONDARY 1	.0010134 (.0399)	.0010566 (.0416)	.0004038 (.0159)
2	.0008788 (.0346)	.0009118 (.0359)	.0004673 (.0184)
3	.0007035 (.0277)	.0007848 (.0309)	.0004572 (.0180)

The measured wear on Build 15 from Posttest 278 to Posttest 297 is as follows:

PUMP END SEAL BUILD 15 WEAR (TESTS 279 THROUGH 297)-m (IN.)			
POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	.0000304 (.0012)	-.0000101 (-.0004)	0
2	-.0000225 (-.0009)	-.0000381 (-.0015)	-.0000127 (-.0005)
3	-.0000076 (-.0003)	-.0000076 (-.0003)	-.0000025 (-.0001)
SECONDARY 1	-.0000381 (-.0015)	.0000304 (.0012)	.0000203 (.0008)
2	-.0000152 (-.0006)	.0000050 (.0002)	.0000431 (.0017)
3	-.0000076 (-.0003)	-.0000025 (-.0001)	-.0000254 (-.0010)

TURBINE END SEAL BUILD 15 WEAR (TESTS 279 THROUGH 297)-m (IN.)			
POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	-.0000381 (-.0015)	-.0000203 (-.0008)	0
2	-.0000152 (-.0006)	-.0000101 (-.0004)	.0000050 (.0002)
3	-.0000279 (-.0011)	-.0000101 (-.0004)	0
SECONDARY 1	.000127 (.0050)	.0001016 (.0040)	-.0000101 (-.0004)
2	-.0000279 (-.0011)	-.0000660 (-.0026)	.0000203 (.0008)
3	-.0002616 (-.0103)	-.0002540 (-.0102)	.0000228 (.0009)

Surface Profile traces (Fig. 106 through 109) of the tapered carbon seal ring indicate the following radial wear from posttest 278 to posttest 297:

POSITION	PUMP END-m (IN.)	TURBINE END-m (IN.)
PRIMARY 1	.0000031 (.000125)	.0000031 (.000125)
2	.0000031 (.000125)	NO WEAR
3	.0000019 (.000078)	.0000031 (.000125)
SECONDARY 1	.0000015 (.000062)	CAN NOT BE DETERMINED
2	NO WEAR	CAN NOT BE DETERMINED
3	.0000015 (.000062)	CAN NOT BE DETERMINED

The surface profile traces of the shaft mating ring sleeve at the seal contact locations (Fig. 110 and 111) indicate no signficant wear except for the turbine end secondary seal which was worn .0000385 m (.001518 in.), after the total test time.

Build 16 Assembly Pretest 298

The tester was reassembled with all new hardware including a new seal housing and shaft sleeve as well as new seal rings. The seal ring to shaft sleeve diametral clearances at assembly are given below:

	PUMP END SEAL-m (IN.)		TURBINE END SEAL-m (IN.)	
	INLET	OUTLET	INLET	OUTLET
PRIMARY	.0002895 (.0114)	.0002489 (.0098)	.0000228 (.0090)	.0002641 (.0104)
SECONDARY	.0002032 (.0080)	.0001651 (.0065)	.0002235 (.0088)	.0001778 (.0070)

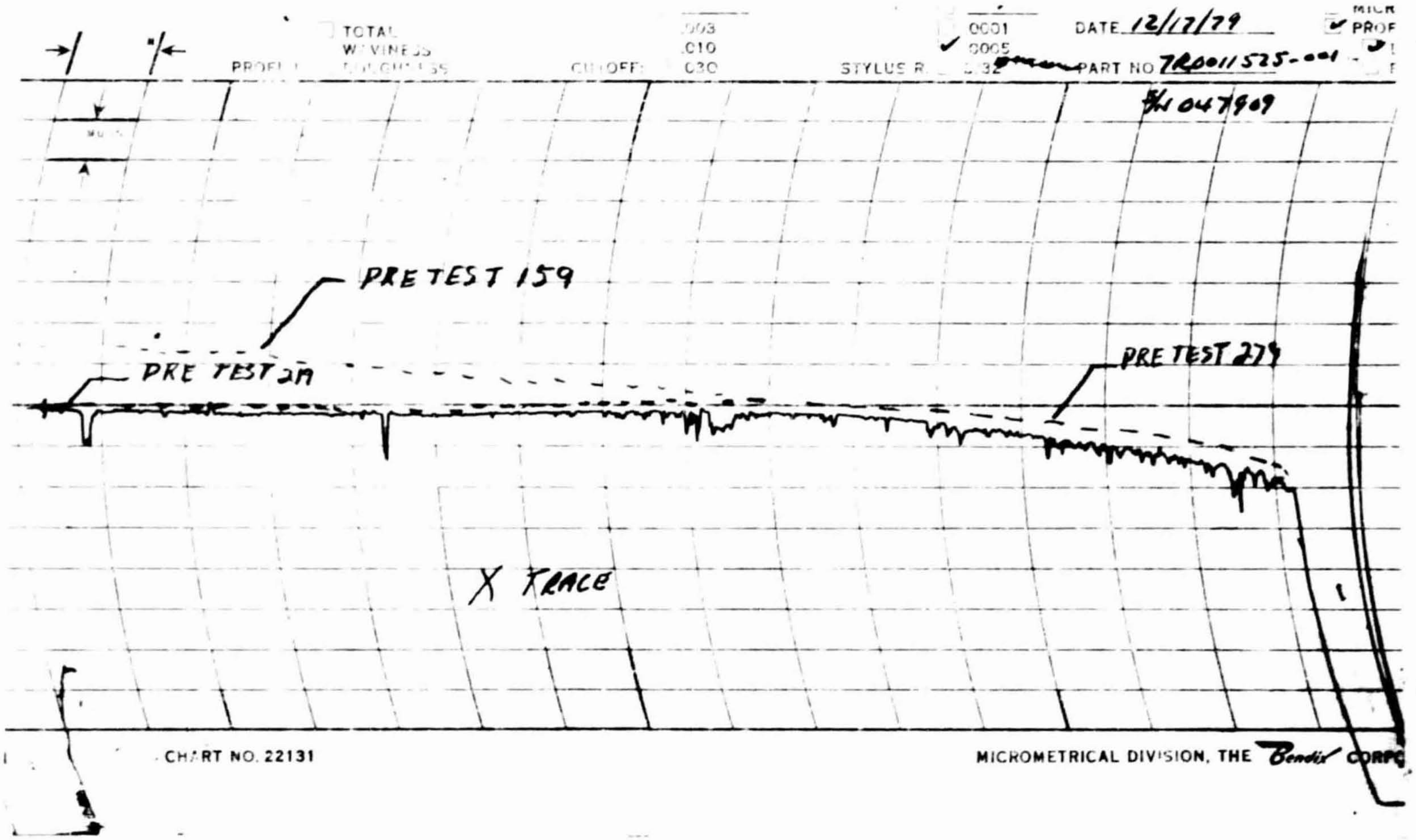


Figure 106. Surface Profile Trace Pump End Primary Seal Ring, P/N 7R0011525, S/N 047909
Build 15, Posttest 297

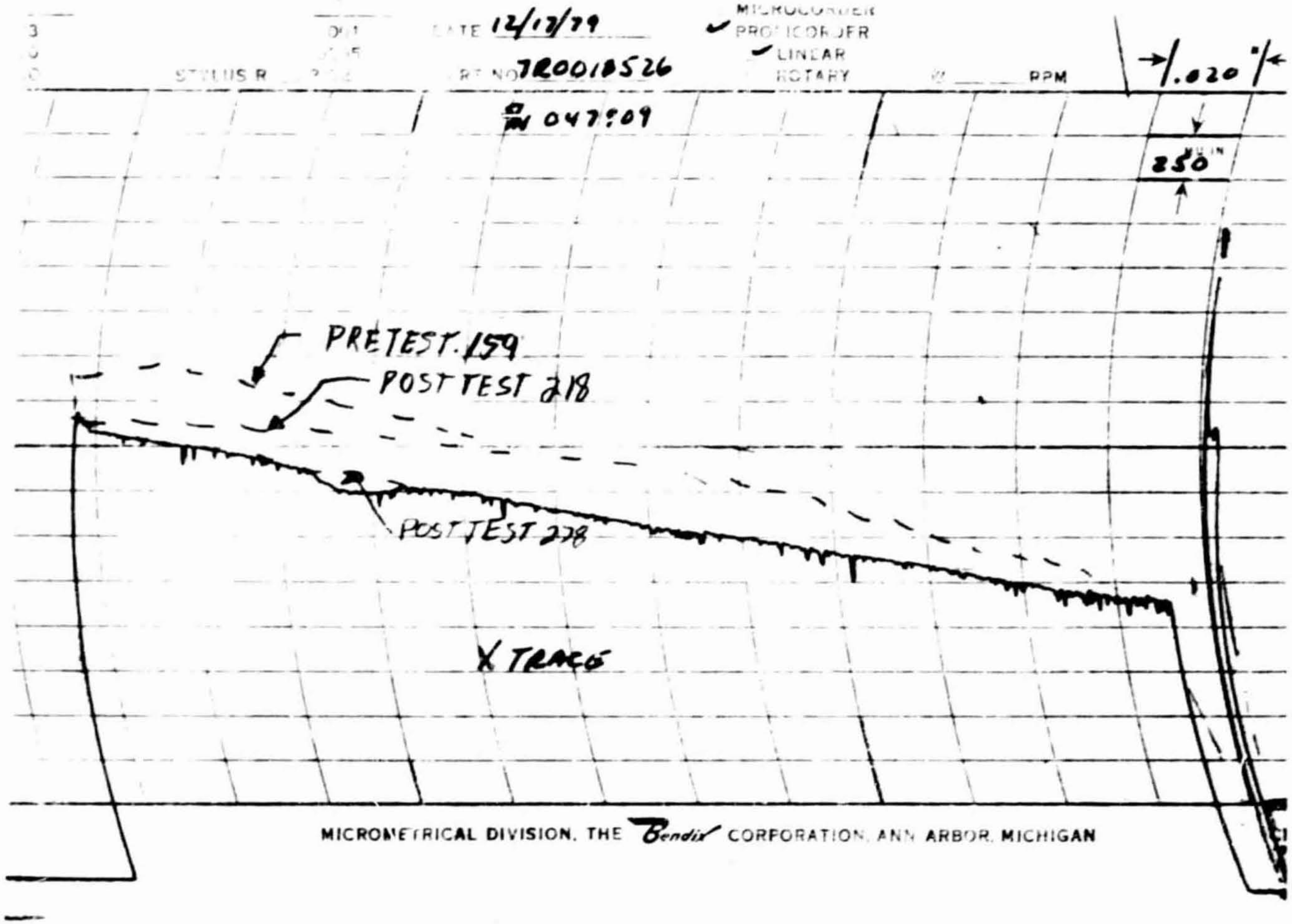


Figure 107. Surface Profile Trace Pump End Secondary Seal Ring, P/N 7R0011526, S/N 047909, Build 15, Posttest 297

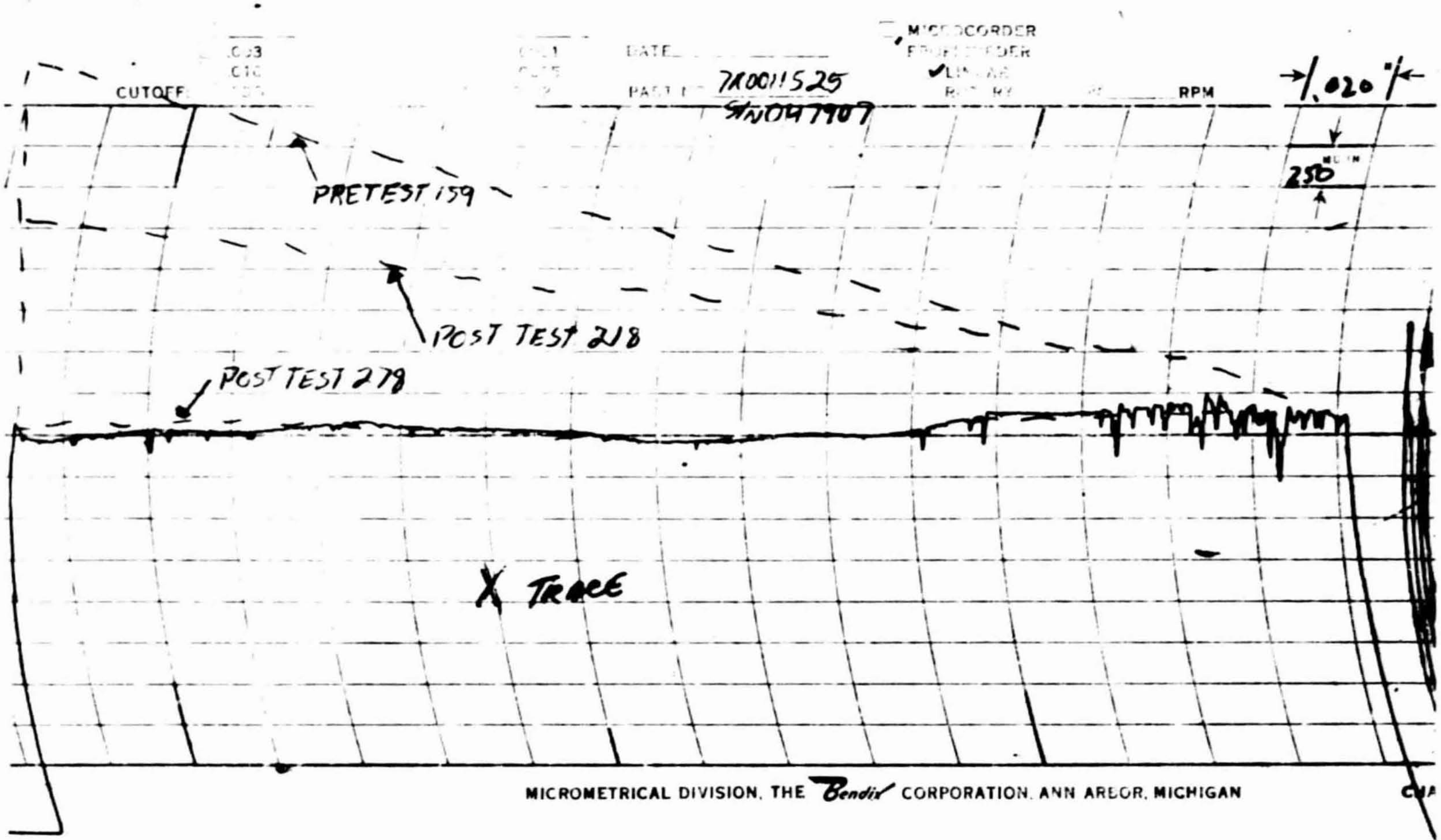


Figure 108. Surface Profile Trace Turbine End Primary Seal Ring, P/N 7R0011525, S/N 047907, Build 15, Posttest 297

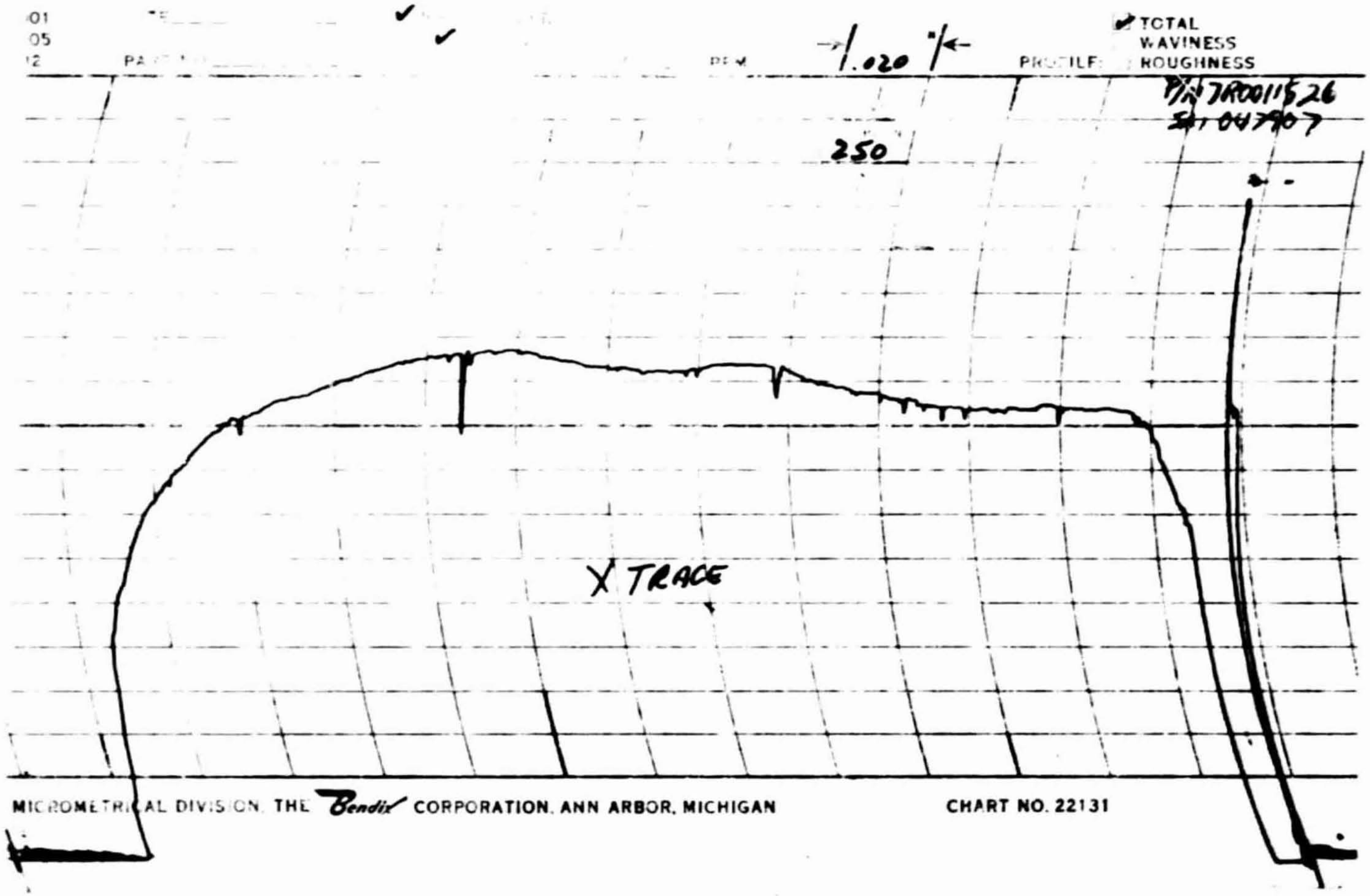
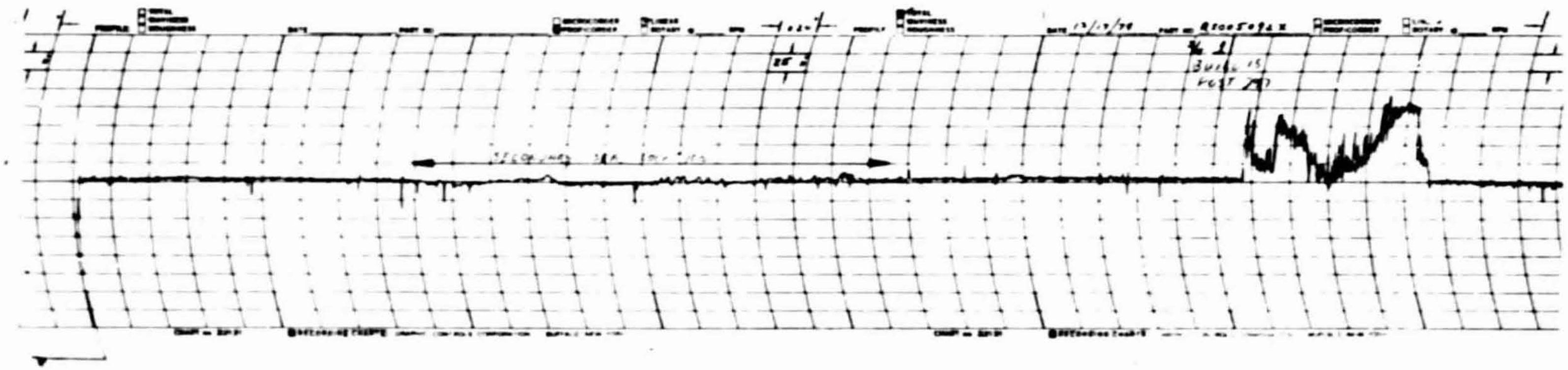
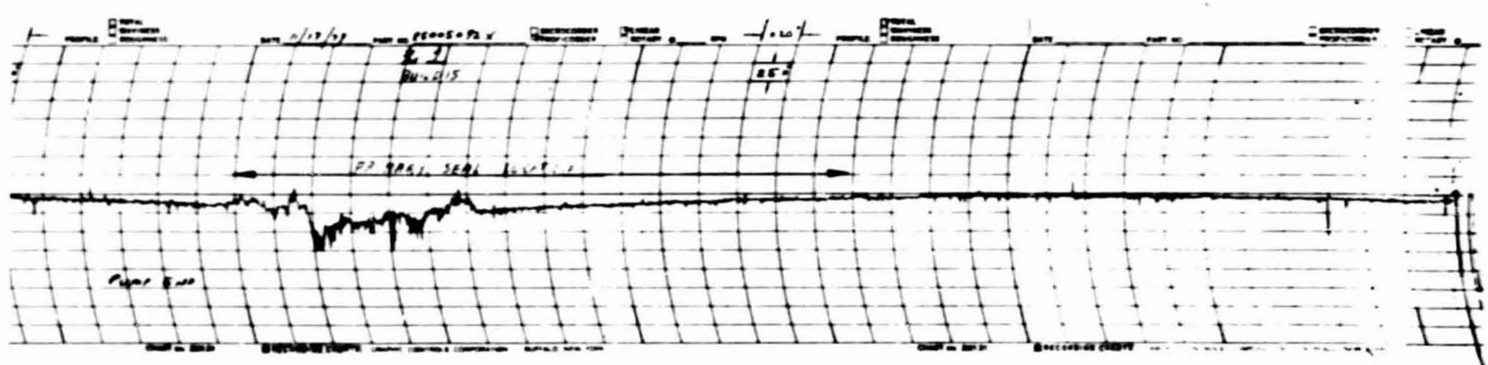


Figure 109. Surface Profile Trace Turbine End Secondary Seal Ring, P/N 7R0011526, S/N 047907, Build 15, Posttest 297

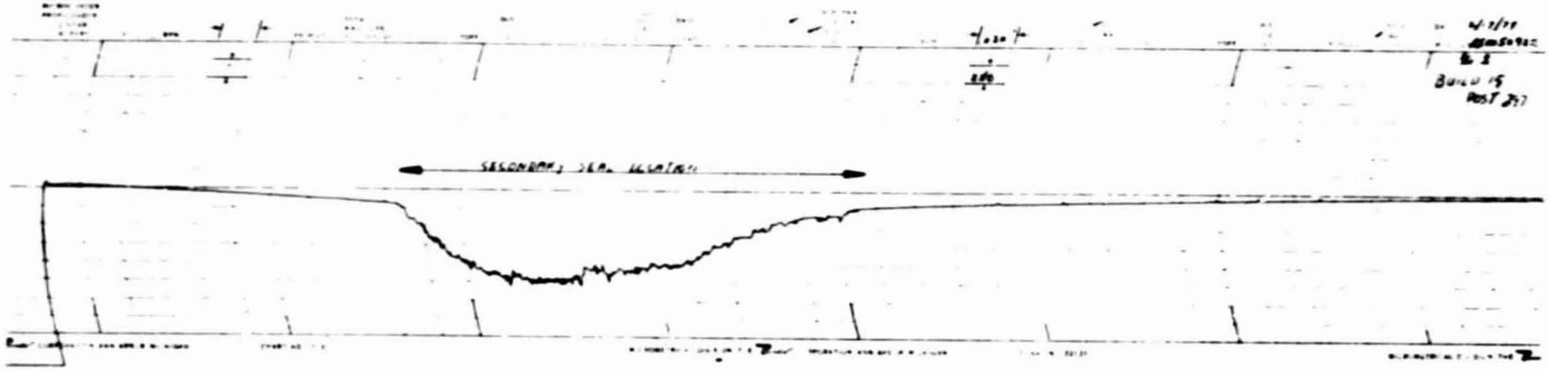


PUMP END SECONDARY SEAL LOCATION

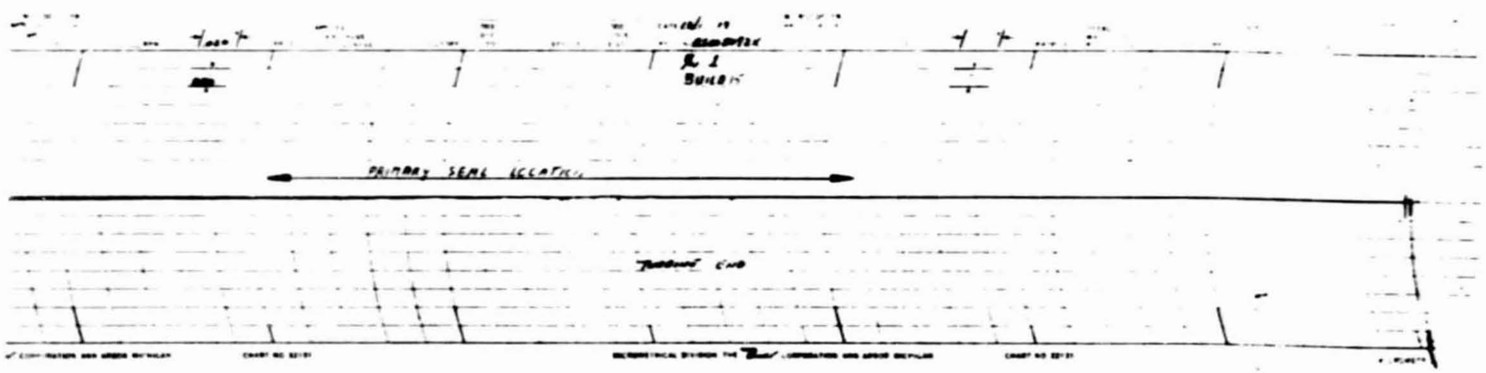


PUMP END PRIMARY SEAL LOCATION

Figure 110. Surface Profile Traces of Tester Mating Ring Sleeve Pump End, P/N RS005092X. S/N 1, Build 15, Posttest 297



TURBINE END SECONDARY SEAL LOCATION



TURBINE END PRIMARY SEAL LOCATION

Figure 111. Surface Profile Traces of Tester Mating Ring Sleeve Turbine End, P/N RS005092X, S/N 1, Build 15, Posttest 297

Tests 298 through 357

The pretest static leakage using ambient temperature gaseous nitrogen was measured at 3447378 n/m^2 (500 psi) pressure increments from 2757902 to 17236893 n/m^2 (400 to 2500 psig). The leakage varied from .1279 kg/sec (.282 lb/sec) at 2757902 n/m^2 (400 psig) to .8278 kg/sec (1.825 lb/sec) at 17236893 n/m^2 (2500 psig). The results are given in Table 12.

The Hot Gaseous Nitrogen Acceleration test series was resumed with a new set of tapered bore carbon seal rings. The shaft speed was ramped to 3036 rad/sec (29,000 rpm) in 10 seconds or less. The seal pressure was increased from 344737**96** to 24131650 n/m^2 (50 to 3500 psig) during the same period. The hot gas temperature was 533K(500 F) at start and gradually decayed to approximately 338K (150 F) at cutoff. A total of 60 tests for 150 minutes was performed to complete the test objective. The results are given in Table 12.

The seal performance was satisfactory with measured total leakage rates of .6350 to .7257 kg/sec (1.4 to 1.6 lb/sec) on the pump end seal and .6350 to .7711 kg/sec (1.4 to 1.7 lb/sec) on the turbine end seal (Table 12). The leakage rates show nearly constant total leakage for the pump end seal of .6803 to .7257 kg/sec (1.5 to 1.6 lb/sec) from start of test through 150 minutes of accumulated test time. The turbine end seal total leakage shows a gradual increase from .6350 to .7257 kg/sec (1.4 to 1.6 lb/sec) at start to .6803 to .7711 kg/sec (1.5 to 1.7 lb/sec) at 150 minutes. The leakage data indicate no significant wear on the pump end seal and gradual wearing of the turbine end seal.

The measured seal drain pressures (Table 12) show fairly constant drain pressures on the pump end primary and secondary seal drains. The turbine end seal showed constant primary drain pressure and gradually increasing secondary drain pressure. The drain pressure data indicate no signficant wear on the pump end primary seal, the pump end secondary seal and the turbine end primary seal. The data indicate gradual wearing of the turbine end secondary seal.

Build 16 Disassembly Posttest 357

The scheduled inspection after 2.5 hours accumulated test time revealed the seals to be in good condition with negligible wear, except for the turbine end secondary seal. The axial sealing dam and bearing pad was worn .0002819 to .0003886 m (.0111 to .0153 in.). The carbon bore was worn 0 to .0000965 m (.0038 in.) diametral on the inlet and 0 to .0000990 m (.0039 in.) diametral on the outlet.

The inspection summary is given in Table 10. The hardware summary is given in Table 7. The measured wear from Pretest 297 to posttest 357 is given below:

PUMP END SEAL BUILD 16 WEAR (TESTS 298 THROUGH 357)-m (IN.)				
POSITION		INLET DIA.	OUTLET DIA.	PAD
PRIMARY	1	-.0000025 (-.0001)	-.0000025 (-.0001)	.0000050 (.0002)
	2	-.0000152 (-.0006)	-.0000127 (-.0005)	.0000127 (.0005)
	3	-.0000050 (-.0002)	-.0000050 (-.0002)	.0000101 (.0004)
SECONDARY	1	0	.0000127 (.0005)	.0000660 (.0026)
	2	.0000254 (.0010)	.0000279 (.0011)	.0000457 (.0018)
	3	-.0000228 (-.0009)	-.0000304 (-.0012)	.0000330 (.0013)

TURBINE END SEAL BUILD 16 WEAR (TESTS 298 THROUGH 357)-m (IN.)				
POSITION		INLET DIA.	OUTLET DIA.	PAD
PRIMARY	1	.0000254 (.0010)	.0000025 (.00010	.0000152 (.0006)
	2	.0000812 (.0032)	-.0000279 (-.0011)	.0000152 (.0006)
	3	.0000279 (.0011)	-.0000431 (-.0017)	.0000127 (.0005)
SECONDARY	1	-.0000300 (-.0013)	-.0000076 (-.0003)	.0003860 (.0162)
	2	.0000152 (.0006)	.00000279 (.0011)	.0002819 (.0111)
	3	.0000965 (.0038)	.0000990 (.0039)	.0003886 (.0153)

The surface profile traces of the shaft mating ring sleeve at the seal contact locations indicate no significant wear, except for the turbine end secondary seal which was worn .0000057 m (.000228 in.).

Build 17 Assembly Pretest 358

The tester was reassembled with the same seal hardware as Build 16. The seal ring to shaft sleeve diametral clearances at assembly are given below:

	PUMP END SEAL-m (IN.)		TURBINE END SEAL-m (IN.)	
	INLET	OUTLET	INLET	OUTLET
PRIMARY	.0002692 (.0106)	.0002286 (.0090)	.0002362 (.0093)	.0002489 (.0098)
SECONDARY	.0001854 (.0073)	.0001600 (.0063)	.0001727 (.0068)	.0001524 (.0060)

Tests 358 through 417

The Hot Gaseous Nitrogen Acceleration Test series was resumed with the same seal hardware as Build 16. The shaft speed was ramped to 3036 rad/sec (29,000 rpm) in 10 seconds or less. The seal pressure was increased from 344737 to 24131650 n/m^2 (50 to 3500 psig) during the same period. The hot gas temperature was 533K (500 F) at start and gradually decayed to approximately 338K (150 F) at cutoff. A total of 60 tests for 150 minutes (2.5 hours) was performed to complete the test objective. The results are given in Table 12.

The seal performance was satisfactory with measured total leakage rates of .6350 to .7711 kg/sec (1.4 to 1.7 lb/sec) on the pump end seal and .5896 to .7257 kg/sec (1.3 to 1.6 lb/sec) on the turbine end seal (Table 12).

The leakage rates adjusted to 24131650 n/m^2 (3500 psig) inlet pressure show gradually increasing leakage for the pump end seal from .6350 to .6803 kg/sec (1.4 to 1.5 lb/sec) at start to .6803 to .7711 kg/sec (1.5 to 1.7 lb/sec) at 300 minutes total accumulated test time. The turbine end leakage shows a cyclical but gradually increasing pattern from .6350 to .6803 kg/sec (1.4 to 1.5 lb/sec) at start to .6803 to .7257 kg/sec (1.5 to 1.6 lb/sec) at 300 minutes total test time. The leakage data indicate gradual wearing of both the turbine end and the pump end seals.

The seal drain pressure data versus test time show nearly constant drain pressure in the pump end primary and turbine end primary drains. The pump end secondary and the turbine end secondary drain pressure both show a slight but gradual increase from start of test through 300 minutes total test time. The data indicate no significant wear of the pump end primary and the turbine end primary seals, and gradual wearing of the pump end secondary and the turbine end secondary seals.

Build 17 Disassembly Posttest 417

The scheduled inspection after 5 hours accumulated test time revealed the seals to be in satisfactory condition. The pump end primary seal was in very good condition with little wear throughout the total accumulated test time. The pump end secondary seal axial sealing dam and bearing pad total wear was .000231 to .0002845 m (.0091 to .0114 in.). The carbon bore was worn .0000838 to .000193 m (.0033 to .0076 in.) diametral on the inlet and 0 to .0002362 m (.0093 in.) diametral on the outlet. Visual inspection of the pump end secondary seal showed some chipping on the downstream edge of the carbon bore at the face and polishing halfway across the bore on the downstream side.

The turbine end primary seal was in good condition with negligible wear. Visual inspection revealed a uniform rubbing contact pattern halfway across the bore on the downstream side. The turbine end secondary seal carbon bore was worn .0000025 to .0001143 m (.0001 to .0045 in.) diametral on the inlet and .0000685 to .0001473 m (.0027 to .0058 in.) diametral on the outlet. The axial sealing dam and bearing pad showed .000345 to .0003835 m (.0136 to .0151 in.) wear. Visual inspection showed uniform rubbing contact across the bore and chipping around the outlet edge. The bearing pads were almost totally worn off. The inspection summary is given in Table 10. The hardware summary is given in Table 7. The measured total wear from pretest 298 to posttest 417 is given below: (negative wear is a **result of measurement tolerances)**

PUMP END SEAL TOTAL WEAR (TESTS 298 THROUGH 417)-m (IN.)			
POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	.0000279 (.0011)	.0000330 (.0013)	.0002354 (.0010)
2	.0000025 (.0001)	-.0000304 (-.0012)	.0000177 (.0007)
3	.0000406 (.0016)	-.0000076 (-.0003)	.0000101 (.0004)
SECONDARY 1	.0001930 (.0076)	.0002362 (.0093)	.0003657 (.0144)
2	.0000838 (.0033)	-.0000127 (-.0005)	.0002311 (.0091)
3	.0000863 (.0034)	.0001473 (.0058)	.000320 (.0126)

TURBINE END SEAL TOTAL WEAR (TESTS 298 THROUGH 417)-m (IN.)			
POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	-.0000203 (.-.0008)	.0000203 (.0008)	-.0000050 (-.0002)
2	-.0001371 (-.0054)	-.0000609 (-.0024)	.0000076 (.0003)
3	-.0000508 (-.0020)	.0000228 (.0009)	.0000228 (.0009)
SECONDARY 1	.0001143 (.0045)	.0001473 (.0058)	.0003454 (.0136)
2	.0000025 (.0001)	.0000685 (.0027)	.0003854 (.0151)
3	.0000330 (.0013)	.0000914 (.0036)	.0003632 (.0143)

The measured wear on Build 17 from Post Test 357 to 417 is as follows:

PUMP END SEAL BUILD 17 WEAR (TESTS 358 THROUGH 417)-m (IN.)			
POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	-.0000304 (-.0012)	.0000508 (.0020)	-.0000177 (-.0007)
2	-.0000355 (-.0014)	-.0000101 (-.0004)	-.0000381 (-.0015)
3	-.0000076 (-.0003)	.0000177 (.0007)	.0000431 (-.0017)
SECONDARY 1	.0002260 (.0089)	.0002362 (.0093)	.0030226 (.0019)
2	.000127 (.0035)	-.0000279 (-.0011)	.0001879 (.0074)
3	.0000990 (.0039)	.0016764 (.0066)	.0002896 (.0114)

TURBINE END SEAL BUILD 17 WEAR (TESTS 358-417)-m (IN.)

POSITION	INLET DIA.	OUTLET DIA.	PAD
PRIMARY 1	.0000152 (.0006)	.0000025 (.0001)	.0000177 (.0007)
2	-.0001651 (-.0065)	-.0000406 (-.0016)	.0000355 (.0014)
3	-.0000254 (-.0010)	.0000457 (.0018)	.0000533 (.0021)
SECONDARY 1	.000127 (.0050)	.0001422 (.0056)	-.0000431 (-.0017)
2	-.0000431 (-.0017)	.0000279 (.0011)	.0000990 (.0039)
3	-.0000533 (-.0021)	.0000025 (.0001)	-.0000279 (-.0011)

Surface profile traces of the tapered carbon seal ring revealed the following radial wear from Pretest 298 to Posttest 417:

POSITION	PUMP END-m (IN.)	TURBINE END-m (IN.)
PRIMARY 1	.0000087 (.000343)	.0000063 (.000250)
2	.0000064 (.000255)	.0000063 (.000250)
3	.0000067 (.000265)	.0000031 (.000125)
SECONDARY 1	NEGLIGIBLE	.0000087 (.000343)
2	NEGLIGIBLE	.0000035 (.000140)
3	.0000063 (.000250)	.00000553 (.000218)

The surface profile traces of the shaft mating ring sleeve at the seal contact locations indicate no significant wear except for the turbine end secondary seal which was worn .0000028m (.0001125 in.) after 5 hours of test time. A ring of carbon residue build up had formed in between the pump end primary and the pump end secondary seal locations as indicated on the pump end surface profile trace.

Build 18 Assembly Pretest 418

The tester was reassembled with the same seal hardware as Build 17. The seal ring to shaft sleeve diametral clearances at assembly are given below:

	PUMP END SEAL-m (IN.)		TURBINE END SEAL-m (IN.)	
	INLET	OUTLET	INLET	OUTLET
PRIMARY	.0002676 (.0103)	.0003022 (.0119)	.0002743 (.0108)	.0002743 (.0108)
SECONDARY	.0004216 (.0166)	.0004191 (.0165)	.0003225 (.0127)	.0003175 (.0125)

Tests 418 through 421

The hot gaseous nitrogen acceleration test series was resumed with the same seal hardware as Build 17. The shaft speed was ramped to 3036 rad/sec (29000 rpm) in 10 seconds or less. The seal pressure was increased from 344737 to 24131650 n/m^2 (50 to 3500 psig) during the same period. The hot gas temperature was 533K (500 F) at start and gradually decayed to approximately 338K (150 F) at cutoff. A total of four tests for 10 minutes were performed. Further testing was delayed pending repair of the facility LN_2 pump. The results are given in Table 12 .

The seal performance was satisfactory with measured total leakage rates of .6350 to .6803 kg/sec (1.4 to 1.5 lb/sec) on the pump end seal and .5896 to .6803 kg/sec (1.3 to 1.5 lb/sec) on the turbine end seal (Table 12).

The leakage rates adjusted to 24131650 n/m^2 (3500 psig) inlet pressure show gradually increasing leakage for the pump end seal from .6350 to .6803 kg/sec (1.4 to 1.5 lb/sec) at start to .7257 to .7711 kg/sec (1.6 to 1.7 lb/sec) at 310 minutes total accumulated test time. The turbine end seal leakage shows a cyclical but gradually increasing pattern from .6350 to .6803 kg/sec (1.4 to 1.5 lb/sec) at start to .6803 to .7257 kg/sec (1.5 to 1.6 lb/sec) at 310 minutes total test time. The leakage data indicate gradual wearing of both turbine end and the pump end seals.

The seal drain pressure data versus test time show nearly constant drain pressure in the pump end primary and turbine end primary drains. The pump end secondary and the turbine end secondary drain pressure both show a slight but gradual increase from start of test through 310 minutes total test time. The data indicate no significant wear of the pump end primary and the turbine end primary seals, and gradual wearing of the pump and secondary and the turbine end secondary seals.

Build 18 Dissassembly Posttest 421

The seal tester was diassembled after 4 runs (10 minutes test time) due to problems with the facility LN_2 pumps. No posttest measurements were taken since the same hardware will be used to compete the test series.

Build 19 Assembly Pretest 422

The tester was reassembled with the same seal hardware as Build 18. No pretest measurements for this build were taken since Build 18 was discontinued after only four tests.

The shaft speed was ramped to 3036 rad/sec (29000 rpm) in 10 seconds or less. The seal pressure was increased from 344737 to 24131650 n/m^2 (50 to 3500 psig) during the same period. The hot gas temperature was 533K (500 F) at start and gradually decayed to approximately 338K (150 F) at cutoff. A total of 12 tests for 30 minutes was performed. Testing was discontinued due to problems with the facility LN_2 pump. Further testing was delayed pending repair of the LN_2 pump. The test results are given in Table 12.

The seal performance was satisfactory with measured total leakage rates of .6803 to .7711 kg/sec (1.5 to 1.7 lb/sec) on the pump end seal and .6350 to .7257 kg/sec (1.4 to 1.6 lb/sec) on turbine end seal (Table 12).

The leakage rates adjusted to 24131650 n/m^2 (3500 psig) inlet pressure show an increase in leakage for the pump end seal from .6350 to .6803 kg/sec (1.4 to 1.5 lb/sec) at start to .7257 to .7711 kg/sec (1.6 to 1.7 lb/sec) at 350 minutes total accumulated test time. The turbine end seal leakage shows a cyclical but gradually increasing pattern from .6350 to .6803 kg/sec (1.4 to 1.5 lb/sec) at start to .6803 to .7257 kg/sec (1.5 to 1.6 lb/sec) at 350 minutes total test time. The leakage data indicate gradual wearing of both the turbine end and the pump end seals.

The seal drain pressure data versus test time show nearly constant drain pressure in the pump end primary and turbine end primary drains. The pump end secondary and the turbine end secondary drain pressures both show a slight but gradual increase from start of testing through 350 minutes total test time.

The data indicate no significant wear of the pump end primary and the turbine end primary seals, and gradual wearing of the pump end secondary and turbine end secondary seals.

Build 19 - Disassembly Posttest 436

The seal tester was disassembled after 15 runs (37.5 minutes test time) due to problems with the facility LN_2 pumps. No post test measurements were taken since the same hardware will be used to complete the test series, once the pumps are repaired.

Build 20 - Assembly Pretest 437

The tester was reassembled using the same seal hardware as Build 19. No pretest measurements for Build 20 were taken due to the short duration of the Build 19 test series.

Tests 437 through 477

The hot gaseous nitrogen acceleration test series was resumed with the same seal hardware as Build 19. The shaft speed was ramped to 3036 rad/sec (29000 rpm) in ten seconds or less. The seal pressure was increased from 344737 to 24131650 n/m^2. (50 to 3500 psig) during the same period. The hot gas temperature was 533K (500 F) at start and gradually decayed to approximately 338K (150 F) at cutoff. A total of 41 tests for 102.5 minutes was performed. An instrumentation problem invalidated leakage data obtained for the first 23 tests; however, the situation was corrected and acceptable data was obtained for the subsequent tests. The results are given in Table 12.

The seal performance was satisfactory with measured total leakage rates of .7257 to .7711 kg/sec (1.6 to 1.7 lb/sec) on the pump end seal and .6350 to .7257 kg/sec (1.4 to 1.6 lb/sec) on the turbine end seal (Table 12. The leakage rates adjusted to 24131650 n/m^2 (3500 psig) inlet pressure (Fig. 112) show gradually increasing leakage for the pump end seal from .6350 to .6803 kg/sec (1.4 to 1.5 lb/sec) at start of test to .7257 to .7711 kg/sec (1.6 to 1.7 lb/sec) at 450 minutes accumulated test time. The turbine end seal total leakage shows a cyclical, but gradually increasing pattern from .6350 to .5896 kg/sec (1.4 to 1.3 lb/sec) at start to .6350 to .7257 kg/sec (1.4 to 1.6 lb/sec) at 450 minutes total test time. The leakage data indicate gradual wearing of both the turbine end and the pump end seals.

The seal drain pressure plots versus test time (Fig. 113) show nearly constant drain pressure in the pump end primary and the turbine end primary drains. The pump end secondary and the turbine end secondary drain pressure both show a slight but gradual increase from start of test through 450 minutes total test time. The data indicate no significant wear of the pump end primary and the turbine end primary seals, and gradual wearing of the pump end secondary and the turbine end secondary seals.

Build 20 Disassembly Post-test 477

The scheduled inspection after 7.5 hours accumulated test time revealed the seals to be in satisfactory condition. The pump end seal was in very good condition with little wear throughout the total accumulated test time. The pump end secondary seal axial sealing dam and bearing pad total wear was .0000325 to .0004114 m (.0128 to .0162 in.). The carbon bore was worn .00001279 to .0001244 m (.0005 to .0049 in.) diametral on the inlet and .0000279 to .0001168 m (.0011 to .0046 in.) diametral on the outlet. Visual inspection of the pump end secondary seal showed some chipping on

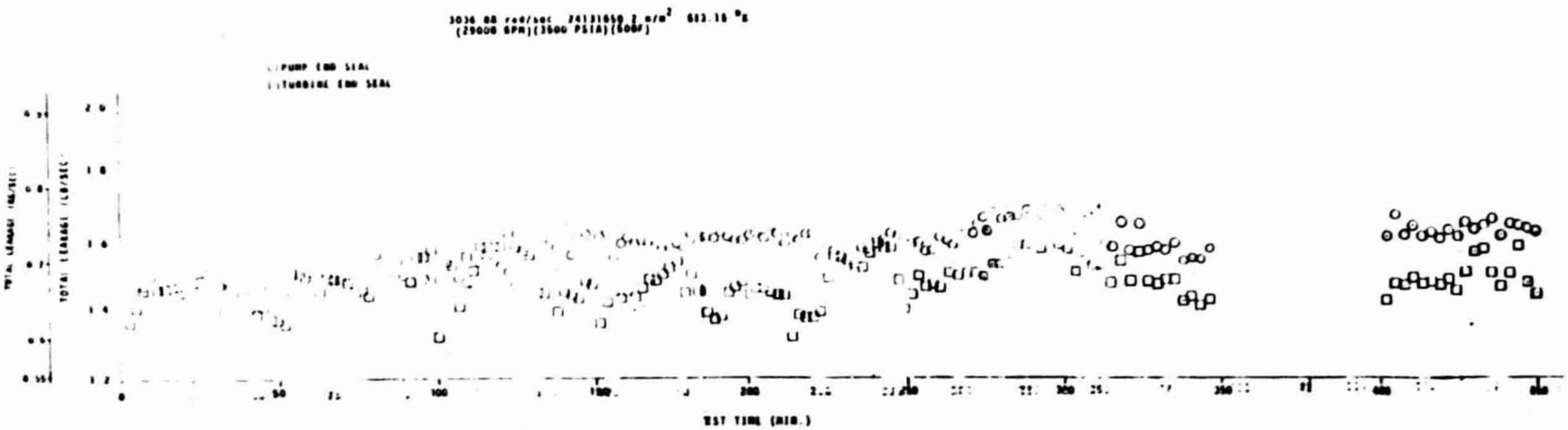


Figure 112. Tapered Bore Seal Total Leakage vs Test Time, Tests 298-477

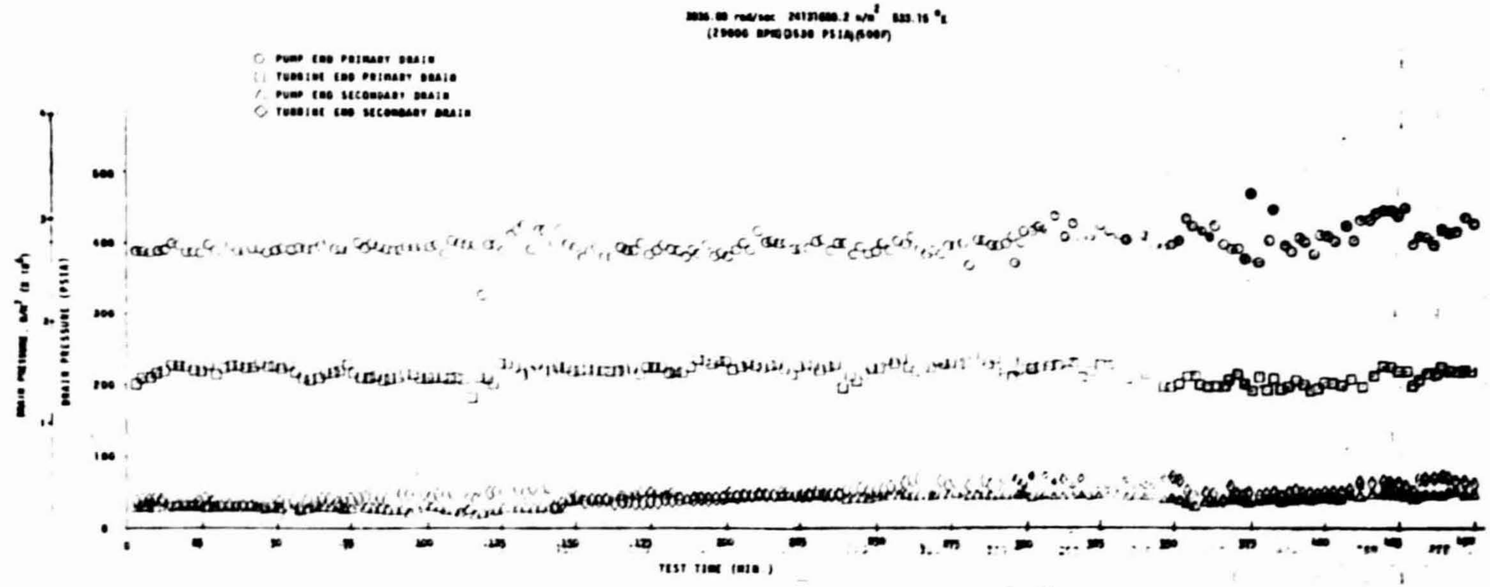


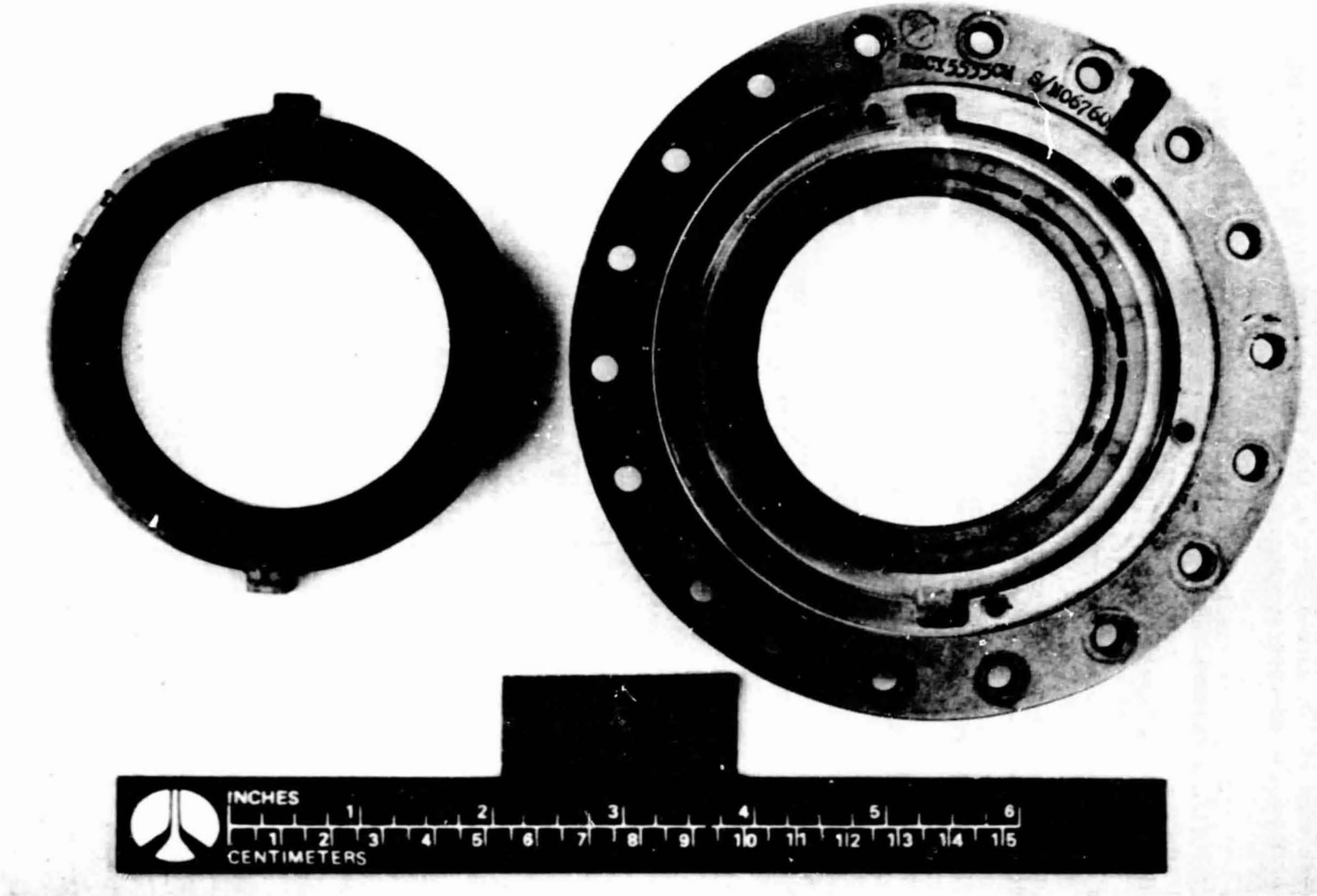
Figure 113. Tapered Bore Seal Drain Pressure vs Test Time, Tests 298-477

the downstream edge of the carbon bore at the face and polishing all the way across the bore on the downstream side.

The turbine end primary seal was in good condition with little wear. Visual inspection revealed a uniform rubbing contact pattern halfway across the bore on the downstream side. The turbine end secondary seal carbon bore total wear was .0000635 to .0001092m(.0025 to .0043 in.) diametral on the inlet and .0000508 to .000114m(.0020 to .0045 in.) diametral on the outlet. The axial sealing dam and bearing pad showed .000414 to .0004368m(.0163 to .0172 in.) wear. Visual inspection showed uniform rubbing contact across the bore and chipping around the outlet edge. The bearing pads were almost totally worn off. The hardware condition is shown on Fig.114 through 122. The inspection summary is given in Table 10 . The hardware summary is given in Table 7 . The measured wear from pretest 298 to posttest 477 is given below:

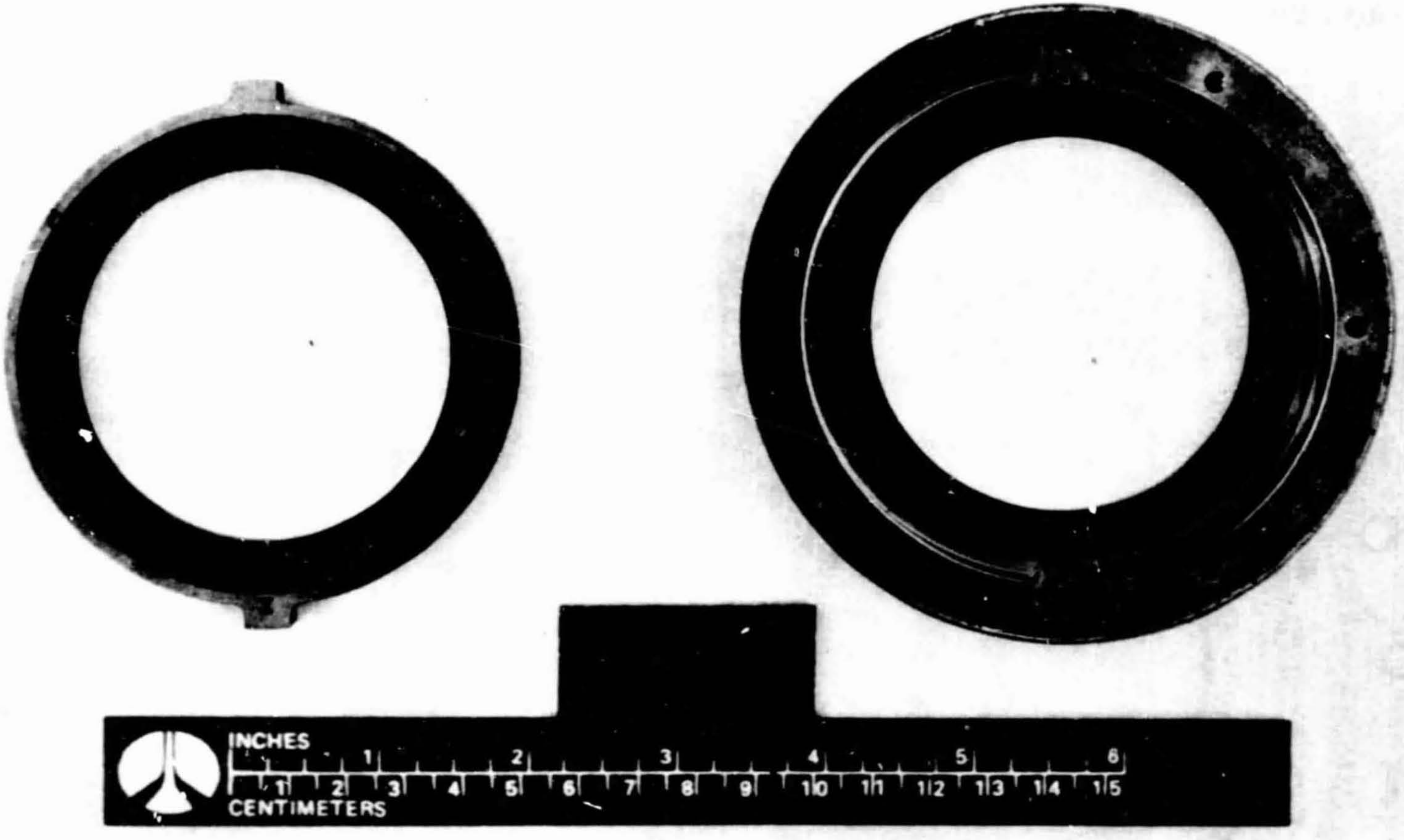
PUMP END SEAL TOTAL WEAR (TESTS 298-477)-m (IN.)				
POSITION		INLET DIA.	OUTLET DIA.	PAD
PRIMARY	1	.0000584 (.0023)	.0000101 (.0004)	.0000076 (.0003)
	2	.0000537 (.0021)	-.0000050 (-.0002)	.0000076 (.0003)
	3	.0000533 (.0021)	-.0000025 (-.0001)	.0000076 (.0003)
SECONDARY	1	.0000127 (.0005)	.0000355 (.0014)	.0003937 (.0155)
	2	.0000152 (.0006)	.0000279 (.0011)	.0003251 (.0128)
	3	.0001244 (.0049)	.0001168 (.0046)	.001524 (.0162)

TURBINE END SEAL TOTAL WEAR (TESTS 298-477)-m (IN.)				
POSITION		INLET DIA.	OUTLET DIA.	PAD
PRIMARY	1	.0000076 (.0003)	.0000177 (.0007)	.0000177 (.0007)
	2	.0000203 (.0008)	-.0000254 (-.0010)	.0000381 (.0015)
	3	.0000152 (.0006)	.0000355 (.0014)	.0000381 (.0015)
SECONDARY	1	.0001092 (.0043)	.0001143 (.0045)	.000414 (.0163)
	2	.0000635 (.0025)	.0000508 (.0020)	.0004368 (.0172)
	3	.0000990 (.0039)	.0000863 (.0034)	.0004267 (.0168)



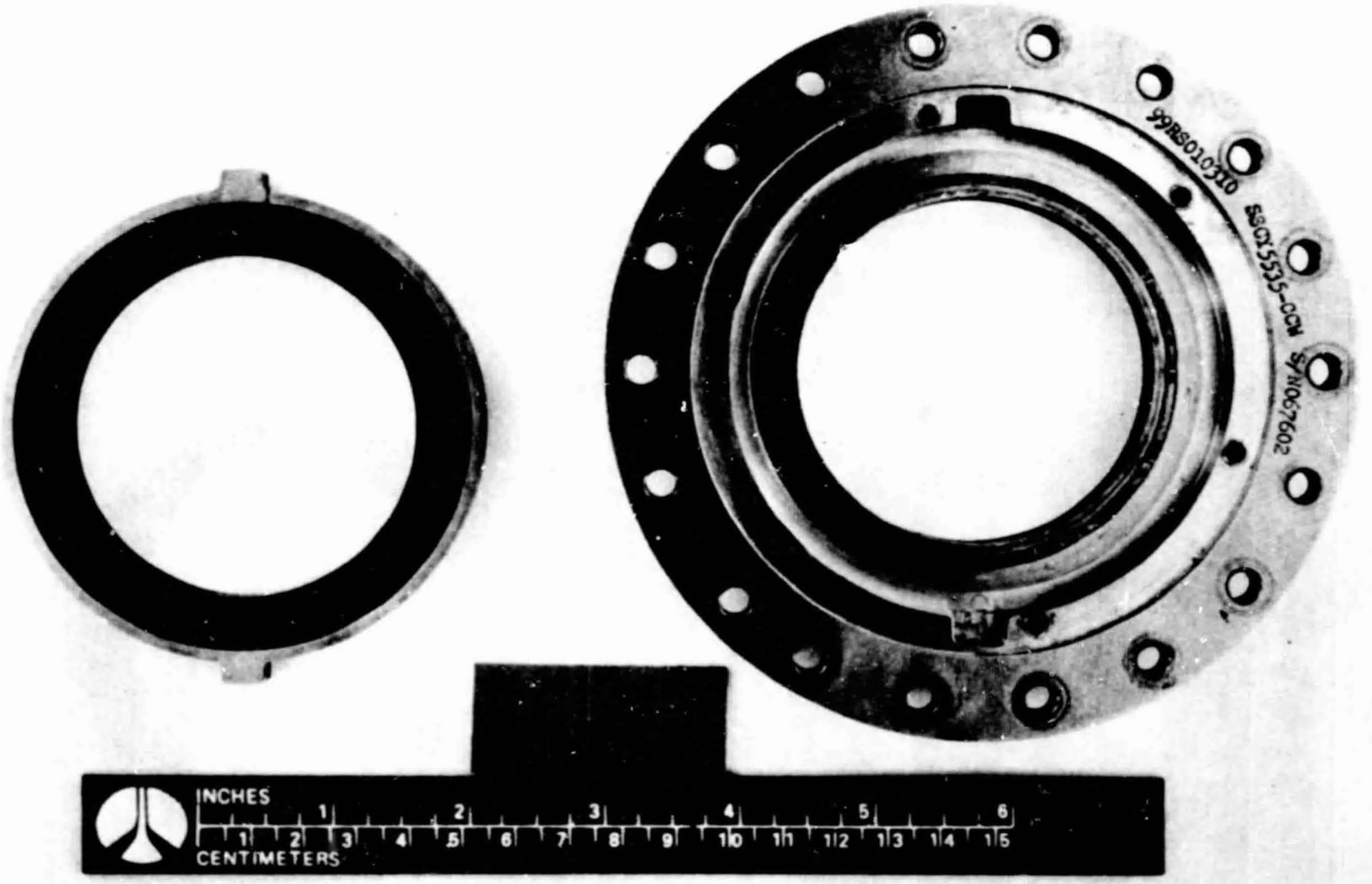
1XY55-5/23/80-C1E

Figure 114. Pump End Primary Seal, P/N 7R0011525, S/N 047905, Build 20, Posttest 477



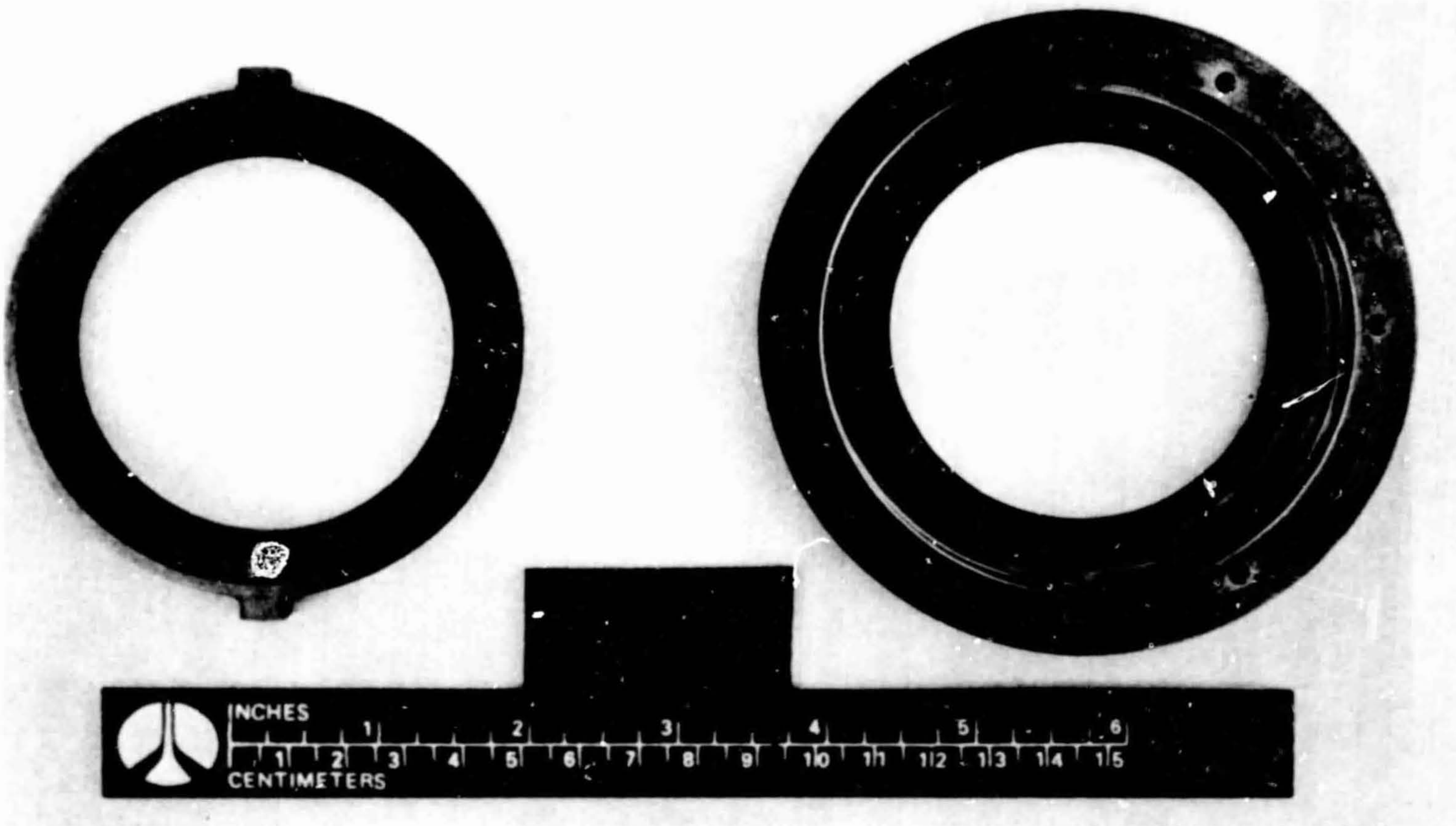
1XY55-5/23/80-C1D

Figure 115. Pump End Secondary Seal, P/N 7R0011526, S/N 047905, Build 20, Posttest 477



1XY55-5/23/80-C1D

Figure 116. Turbine End Primary Seal, P/N 7R0011525, S/N 047908, Build 20, Posttest 477



1XY55-5/23/80-C1C

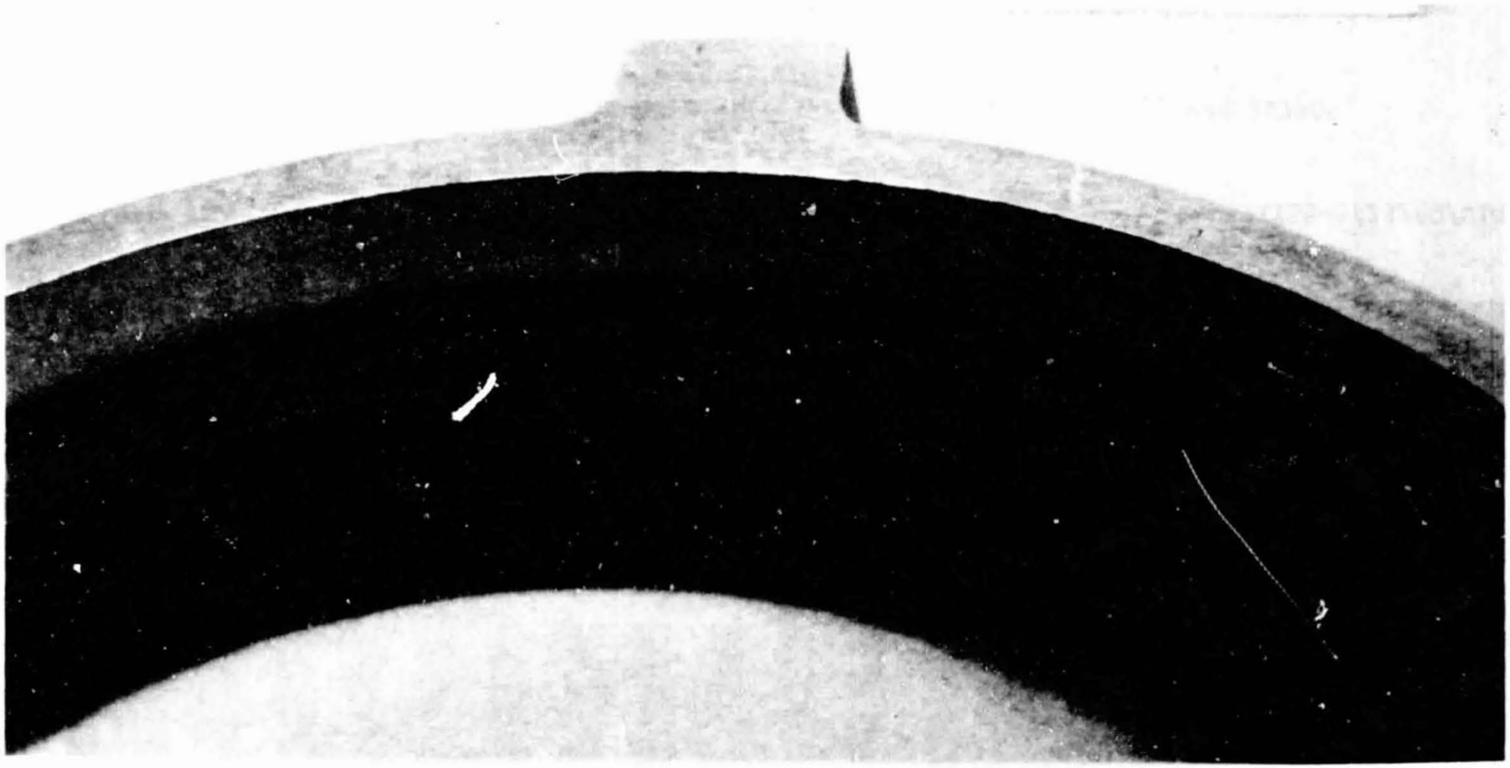
Figure 117. Turbine End Secondary Seal, P/N 7R0011526, S/N 047903, Build 20, Posttest 477

1XY55-5/23/80-C1F

Figure 118. Pump End Primary Seal Ring P/N 7R0011525, S/N 047905,
Build 20, Posttest 477

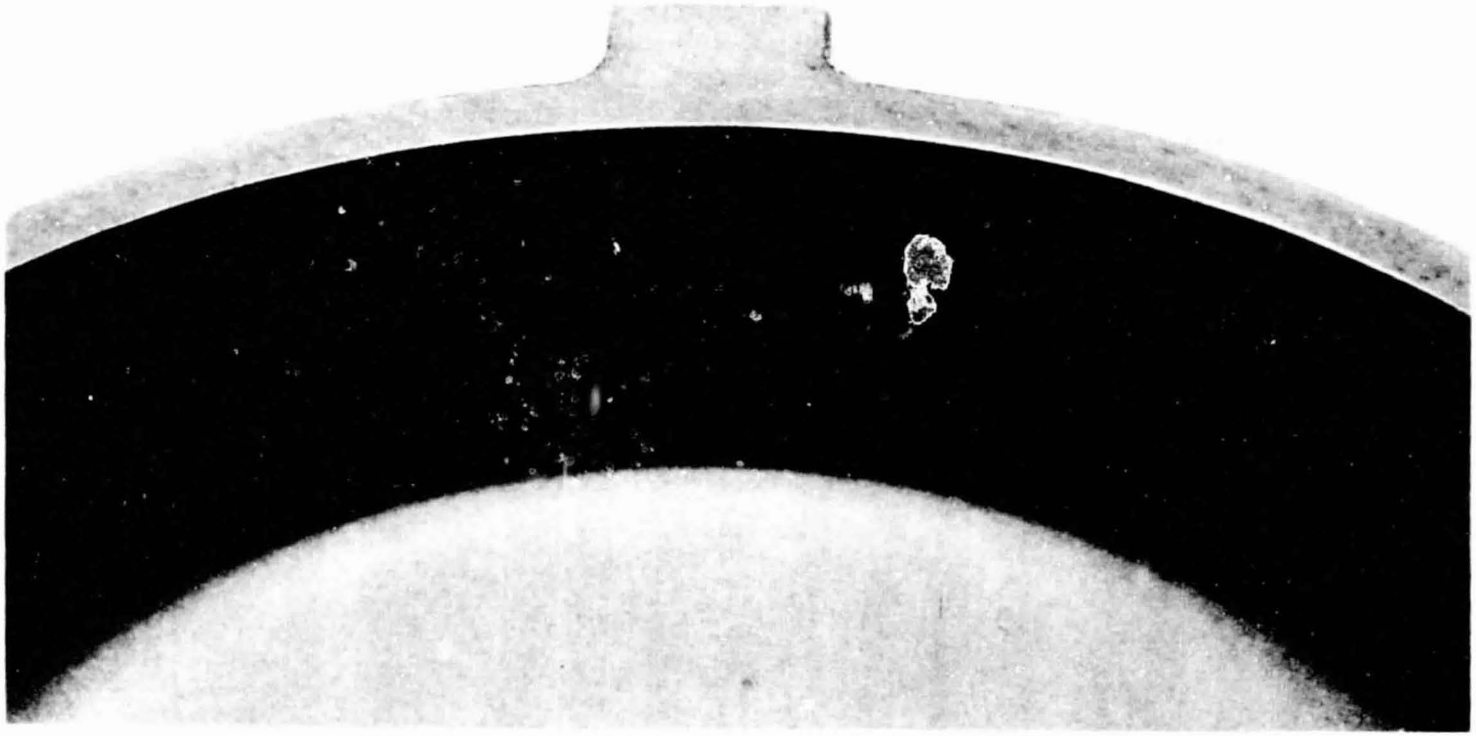
1XY55-5/23/80/C1G

Figure 119. Pump End Secondary Seal Ring P/N 7R0011526, S/N 047905, Build 20, Posttest 477



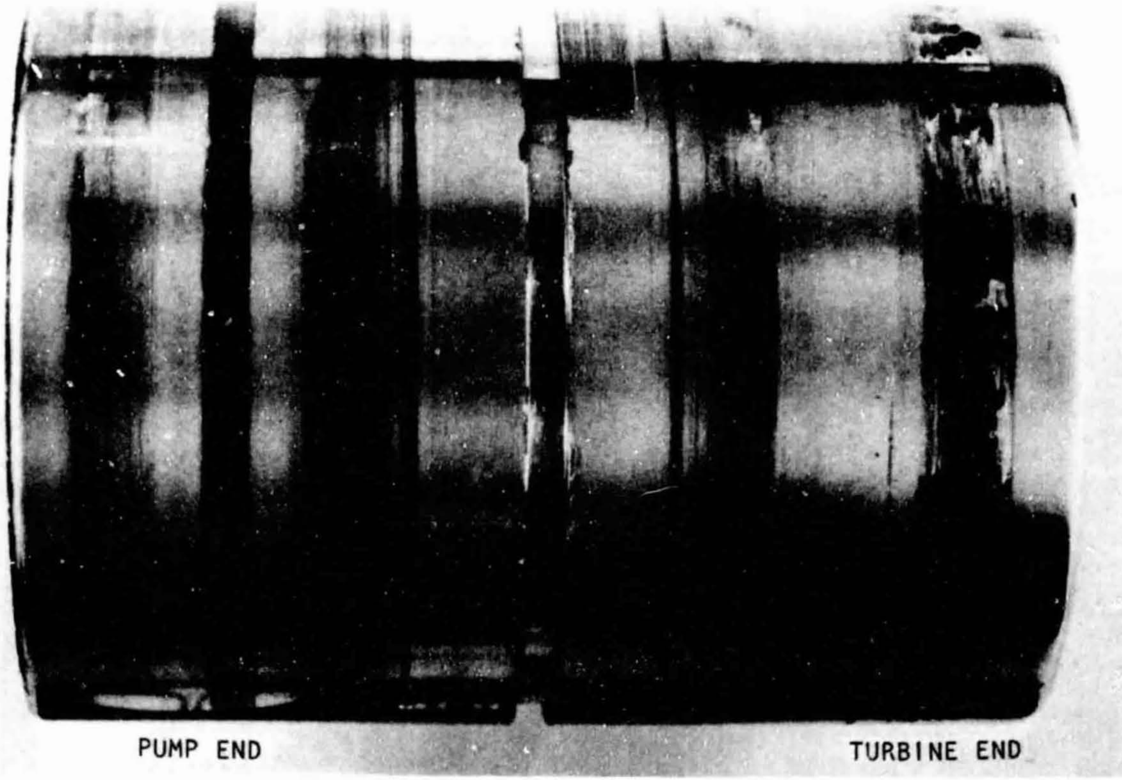
1XY55-5/23/80-C1H

Figure 120. Turbine End Primary Seal Ring, P/N 7R0011525, S/N 047908, Build 20, Posttest 477



1XY55-5/23/80-C1I

Figure 121. Turbine End Secondary Seal Ring, P/N 7R0011526, S/N 047903, Build 20, Posttest 477



1XY55-5/23/80-C1A

Figure 122. Mating Ring Sleeve, P/N RS05092X-005, S/N 2, Build 20, Posttest 477

The measured wear on build 18, 19 and 20 from post-test 417 to test 477 is as follows:

PUMP END SEAL BUILD 18, 19 and 20 WEAR (TESTS 417-477)-m (IN.)				
POSITION		INLET DIA.	OUTLET DIA.	PAD
PRIMARY	1	.0000304 (.0012)	-.0000228 (-.0009)	-.0000177 (-.007)
	2	.0000508 (.0020)	.0000254 (.0010)	-.0000101 (-.0004)
	3	.0000127 (.0005)	.0000050 (.0002)	-.0000025 (-.0001)
SECONDARY	1	-.0001803 (-.0071)	-.000206 (-.0079)	.0000279 (.0011)
	2	-.0000685 (-.0027)	-.00000351 (-.00014)	.0000939 (.0037)
	3	.0000381 (.0015)	-.00003041 (-.0012)	.0000914 (.0036)

TURBINE END SEAL BUILD 18, 19 and 20 WEAR (TESTS 417-477)-m (IN.)				
POSITION		INLET DIA.	OUTLET DIA.	PAD
PRIMARY	1	.0000279 (.0011)	-.0000025 (-.0001)	.0000229 (.0009)
	2	.0001041 (.0041)	.0000355 (.0014)	.0000304 (.0012)
	3	.0000660 (.0026)	.0000127 (.0005)	.0000152 (.0006)
SECONDARY	1	-.0000050 (-.0002)	-.0000330 (-.0013)	.0000685 (.0027)
	2	.0000609 (.0024)	-.0000177 (-.0007)	.0000533 (.0021)
	3	.0000660 (.0026)	-.0000050 (-.0002)	.0000635 (.0025)

Surface profile traces (Fig. 123 through 126)of the tapered carbon seal ring indicate the following radial wear from pretest 298 to posttest 477:

POSITION		PUMP END-m (IN.)	TURBINE END-m (IN.)
PRIMARY	1	.0000110 (.000437)	.0000064 (.0000252)
	2	.0000036 (.000145)	.0000043 (.000172)
	3	.0000063 (.000250)	.0000063 (.000250)
SECONDARY	1	.0000063 (.000250)	.0000058 (.000230)
	2	.0000063 (.000250)	.0000047 (.000187)
	3	.0000063 (.000250)	.0000055 (.000218)

The surface profile traces of the shaft mating ring sleeve at the seal contact locations (Fig. 127 through 128)indicate no significant wear except for the turbine and secondary seal which was worn .0000028 m (.0001125 in.) after 7.5 hours test time. A ring of carbon residue buildup had formed in between the pump end primary and the pump end secondary seal locations as indicated on the sleeve pump end surface profile trace.

Discussion - Builds 12 through 20

Two sets of tapered bore seals were used for 362 starts for 905 minutes of hot gas acceleration testing at 3036 rad/sec (29000 rpm) and 24131650 n/m^2 (3500 psig) GN_2 inlet pressure and nine assemblies.

Build 12 was tested for 43 starts and 107.5 minutes at 24131650 n/m^2 (3500 psig). The seal performance was satisfactory with measured leakage rates of approximately .6350 to .7257 kg/sec (1.4 to 1.6 lb/sec). The seals were in good condition with negligible wear except for the turbine end secondary seal which was worn a total of .0003937 m (.0155 in.) in the pad height dimension. The carbon bore was worn .0001295 to .0002717 m (.0051 to .0107 in.) diametral on the inlet and .0000762 to .0002464 m (.003 to .000 in.) diametral on the outlet. Testing was discontinued due to a bearing failure which could have contributed to the seal wear.

Build 13 was tested with new hardware for 60 starts for 150 minutes at acceleration testing conditions, in addition to pretest static leakage tests. The seal performance was satisfactory with measured total leakage rates of .5896 to .6803 kg/sec (1.3-1.5 lb/sec) on the pump end seal and .6803 to .8164 kg/sec (1.5 to 1.8 lb/sec) on the turbine end seal. The seals were in good condition with negligible wear except for the turbine end secondary seal. The axial sealing dam and bearing pad was worn .0003124 to .0003911 m (.0123 to .0154 in.). The carbon bore was worn 0 to .0001498 m (.0059 in.) diametral on the inlet and 0 to .0001905 m (.0075 in.) diametral on the outlet.

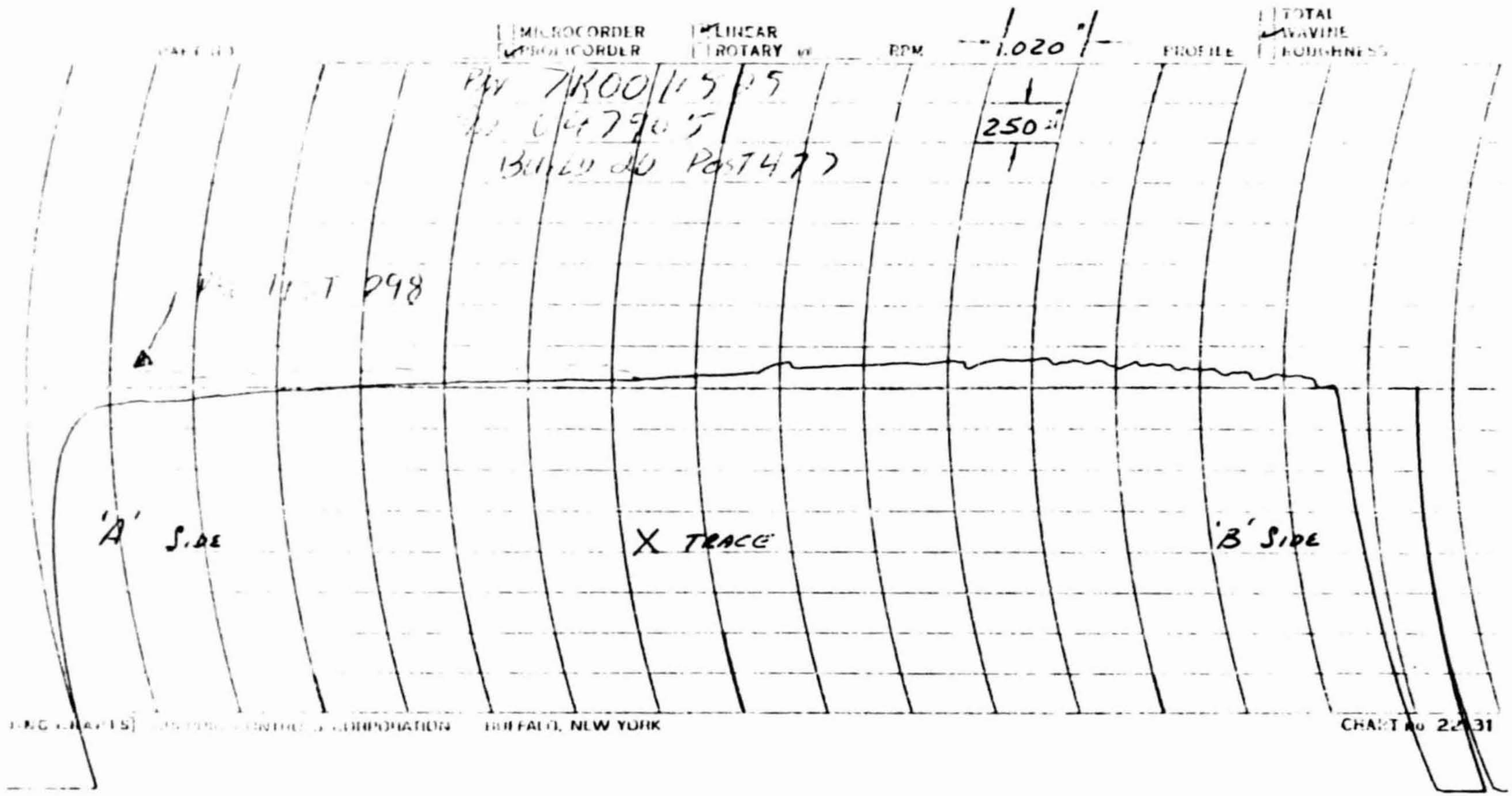


Figure 123. Surface Profile Trace Pump End, Primary Seal Ring, P/N 7R0011525, S/N 047905, Build 20, Posttest 477

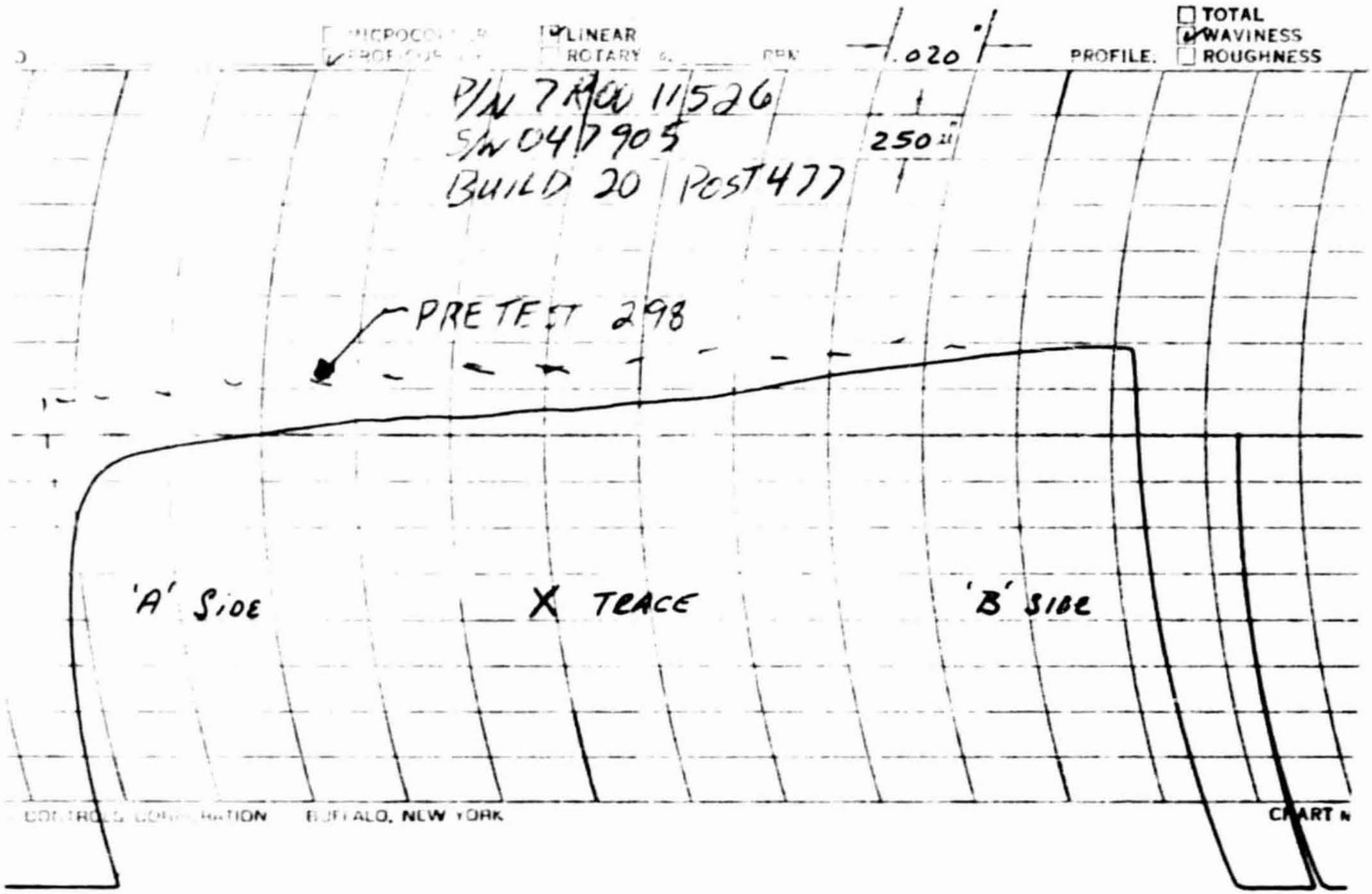


Figure 124. Surface Profile Trace Pump End, Secondary Seal Ring, P/N 7R0011526, S/N 047905, Build 20, Posttest 477

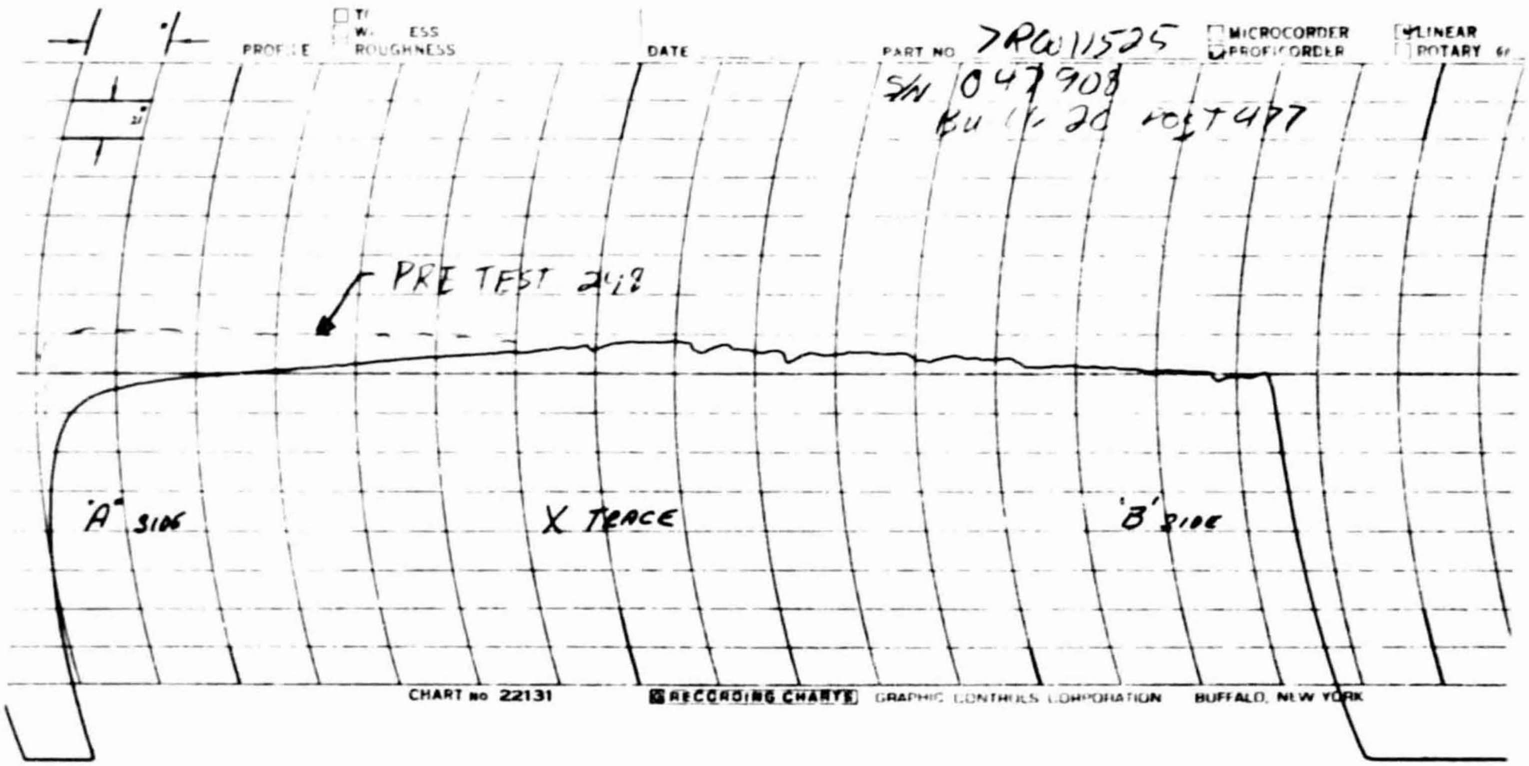


Figure 125. Surface Profile Trace Turbine End, Primary Seal Ring, P/N 7R0011525, S/N 047908, Build 20, Posttest 477

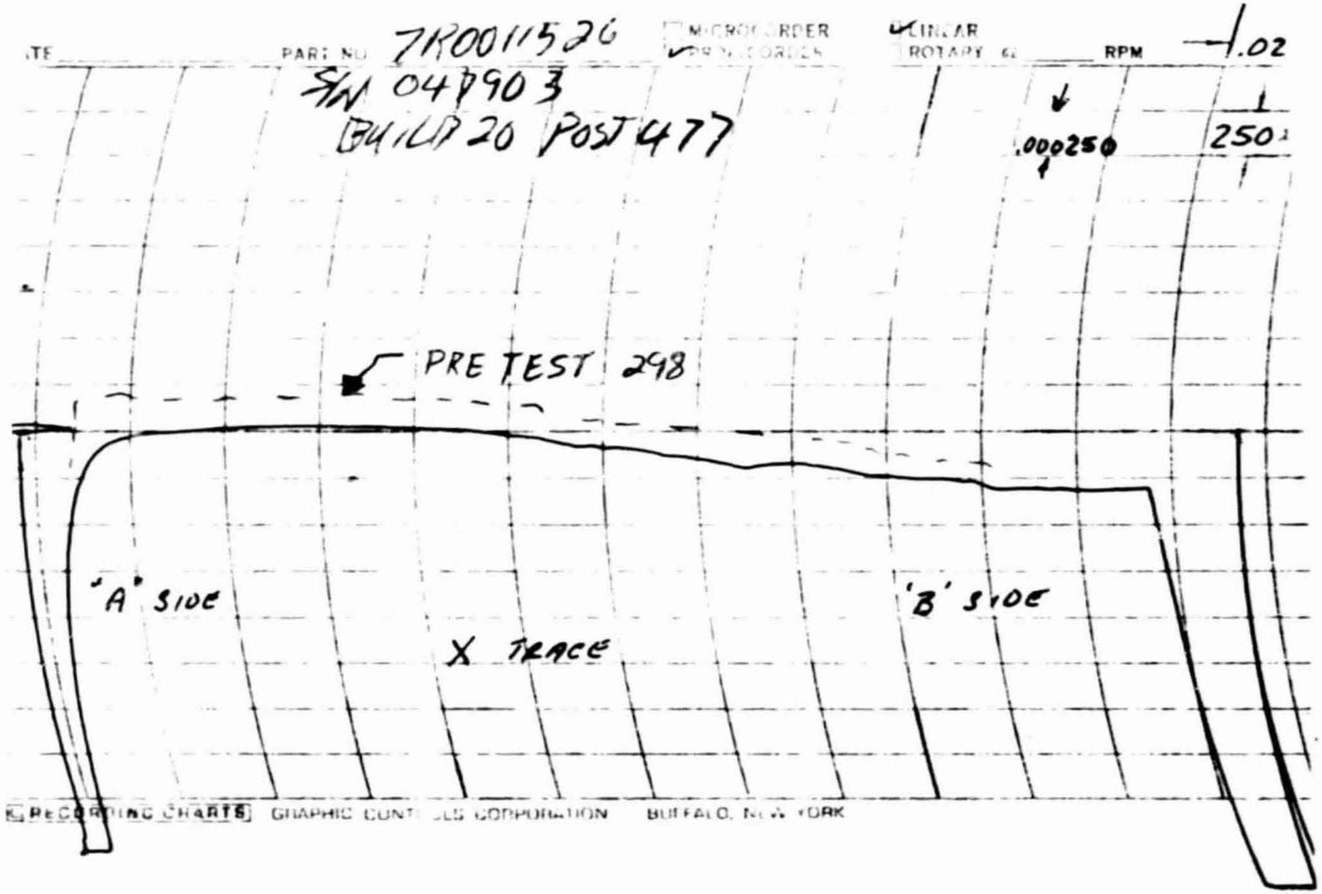
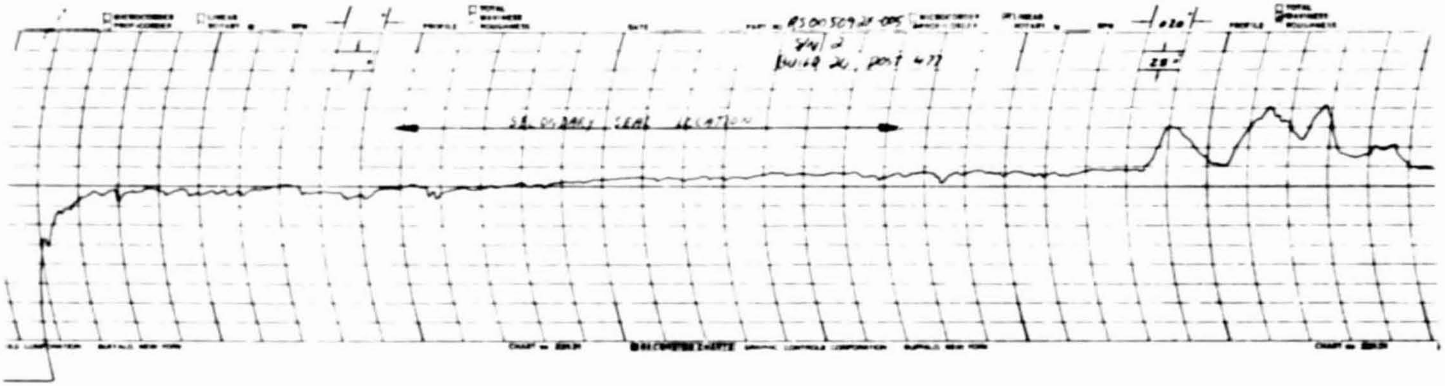
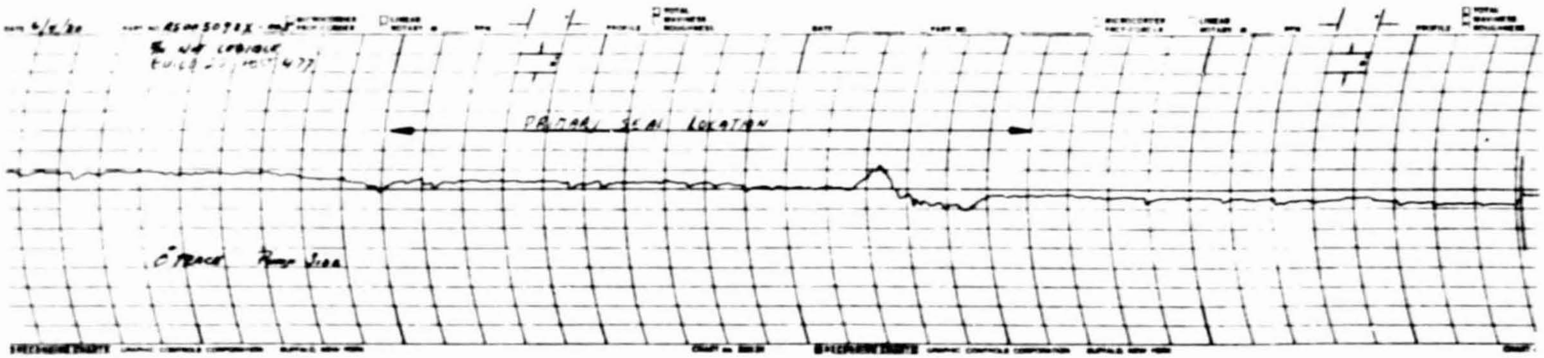


Figure 126. Surface Profile Trace Turbine End, Secondary Seal Ring, P/N 7R0011526, S/N 047903, Build 20, Posttest 477

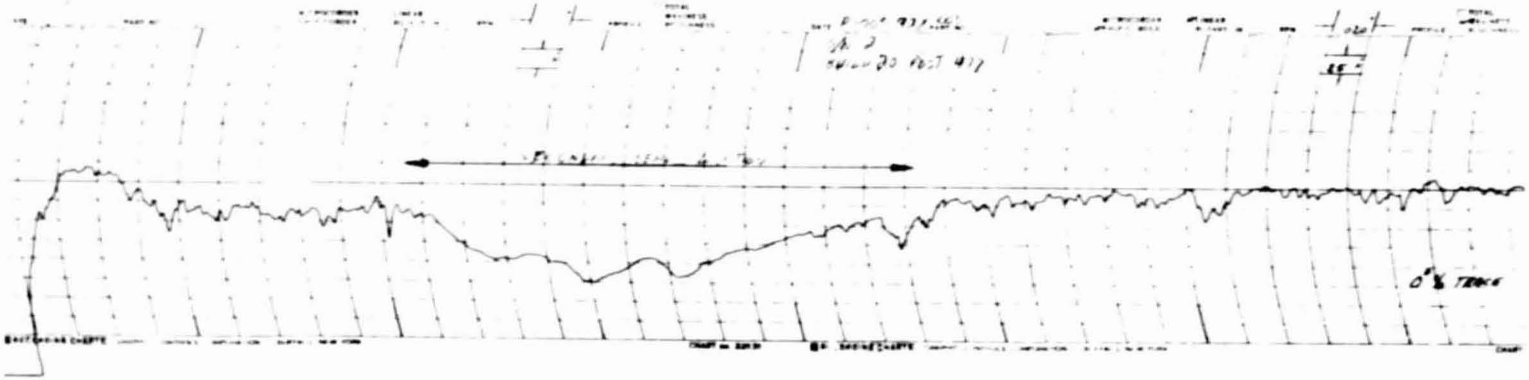


Pump End Secondary Seal Location

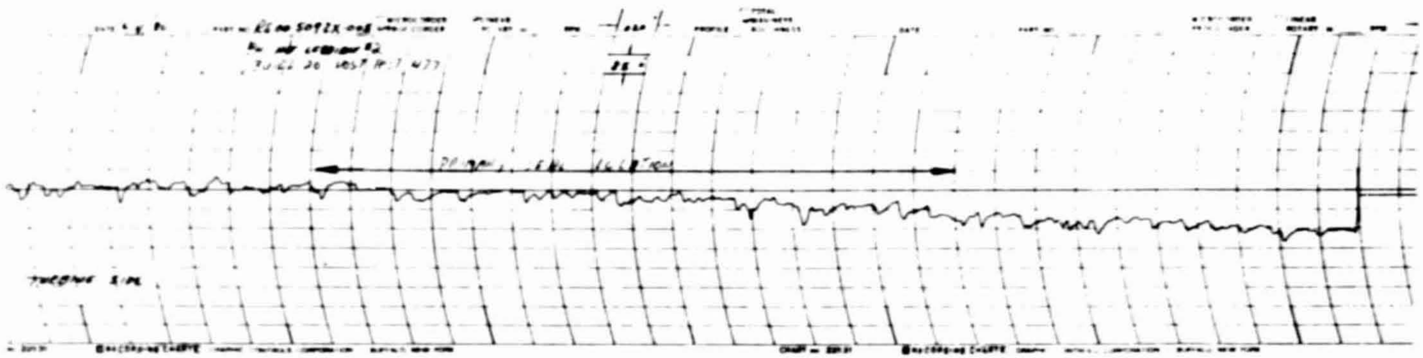


Pump End Primary Seal Location

Figure 127. **Surface Profile Traces of Testing Mating Ring Sleeve Pump End, P/N RS005092X-005, S/N 2, Build 20, Posttest 477**



Turbine End Secondary Seal Location



Turbine End Primary Seal Location

Figure 128. Surface Profile Traces of Testing Mating Ring Sleeve Turbine End, P/N RS005092X-005, S/N 2, Build 20, Posttest 477

Build 14 was tested for 60 starts and 150 minutes (scheduled duration) at 533K (500 F), 3036 rad/sec (29000 rpm) and 24131650 n/m^2 (3500 psig). Seal performance was satisfactory with measured total leakage rates of .680 to .7257 kg/sec (1.5 to 1.6 lb/sec) on the pump end seal and .7711 to .8618 kg/sec (1.7 to 1.9 lb/sec) on the turbine end seal. The seals were in good condition with negligible wear except for the turbine end secondary seal. The axial sealing dam and lift pads were completely worn off at one place. The carbon bore was worn .0008864 to .0009652 m (.0349 to .0380 in.) diametral on the inlet and .0009550 to .001044 m (.0376 to .0411 in.) diametral on the outlet. Most of the total wear occurred during this build.

Build 15 was tested for 19 runs and 47.5 minutes at acceleration test conditions to complete the testing on the first set of seals. The seal performance was satisfactory with measured total leakage rates of .6350 to .7257 kg/sec (1.4-1.6 lb/sec) on the pump end seal and .7711 to .9525 kg/sec (1.7 to 2.1 lb/sec) on the turbine end seal. The primary seals were in good condition with little wear. The pump end secondary seals showed some wear on the lift pads but a negligible amount on the carbon bore. The turbine end secondary seal lift pads were worn off over one-third of the face and the carbon bore chipped on the downstream edge.

Build 16 was tested with new hardware for 60 starts and 150 minutes of acceleration test conditions. Pretest static leakage tests were also conducted. The seal performance was satisfactory with measured total leakage rates of .6350 to .7257 kg/sec (1.4 to 1.6 lb/sec) on the pump end seals and .6350 to .7711 kg/sec (1.4 to 1.7 lb/sec) on the turbine end seals. The seals were in good condition with negligible wear except for the turbine end secondary seal which was worn in the pad height dimension.

Build 17 was tested for 60 starts and 150 minutes at acceleration test conditions. The seal performance was satisfactory with total measured leakage rates of .6350 to .7711 kg/sec (1.4 to 1.7 lb/sec) on the pump end seals and .5896 to .7257 kg/sec (1.3 to 1.6 lb/sec) on the turbine end seals. The two primary seals were in good condition with negligible wear. The pump end secondary seal was worn on the pad height and carbon bore dimensions. The turbine end secondary seal total wear was .0003454 to .0003835 m (.0136 to .0151 in.) on the pad height dimension and .0000025 to .0001473 m (.0001 to .0058 in.) on the carbon bore.

Build 18 was tested for 4 starts for 10 minutes at acceleration test conditions. The seal performance was satisfactory with measured total leakage rates of .6350 to .6803 kg/sec (1.4 to 1.5 lb/sec) on the pump end seal and .5896 to .6803 kg/sec (1.3 to 1.5 lb/sec) on the turbine end seal. Testing was discontinued due to problems with the facility LN_2 pumps. No posttest inspections were done since the same seal hardware will be used to complete the test series when the pumps are fixed.

Build 19 was tested for 15 starts for 37.5 minutes at acceleration test conditions. The seal performance was satisfactory with measured total leakage rates of .6803 to .7711 kg/sec (1.5 to 1.7 lb/sec) on the pump end seal and .6350 to .7257 kg/sec (1.4 to 1.6 lb/sec) on the turbine end seal. Testing was discontinued due to problems with the facility LN_2 pumps. No posttest measurements were taken since the same seal hardware will be used to complete the test series once the pumps are repaired.

Build 20 was tested for 41 starts for 102.5 minutes at acceleration test conditions to complete testing for the program. The seal performance was satisfactory with total measured leakage rates of .7257 to .7711 kg/sec (1.6 to 1.7 lb/sec) on the pump end seal and .6350 to .7257 kg/sec (1.4 to 1.6 lb/sec) on the turbine end seal. The primary seals were in good condition with little wear. The pump end secondary seal was worn .0003251 to .0004114 m (.0128 to .0162 in.) on the pad height dimension and was chipped on the downstream edge of the carbon bore. The turbine end secondary seal was worn .0004140 to .0004368 m (.0163 to .0172 in.) on the pad height dimension and was chipped on the outlet edge of the bore. The shaft sleeve showed no appreciable wear.

CONCLUSIONS

1. The tapered bore hydrostatic floating ring shaft seal is feasible for high-pressure hot-gas seals. Theoretical analysis indicates that the convergent tapered bore provides a significant increase in centering force compared to the straight bore or Rayleigh step. Satisfactory operation was demonstrated for 370 starts and 15.93 hours total at approximately 24132500 n/m^2 (3500 psig), 533K (500 F), and 3142 rad/sec (30000 rpm).

   a. The results indicate that the analysis procedures are adequate to predict the seal performance.

   b. The hydrostatic centering force exceeds the radial friction force by a significant margin.

   c. The optimum ratio of the inlet clearance to the outlet clearance is 1.8.

   d. The data indicate negligible wear of the primary seal rings and gradual but acceptable wearing of the secondary seal rings.

   e. The measured leakage of 0.59 to 0.77 kg/sec (1.3 to 1.7 lb/sec) on the pump end seal compared to the calculated leakage of 0.59 kg/sec (1.3 lb/sec) indicates that the seal was operating with a slightly larger clearance than predicted.

2. The Rayleigh step hydrodyanmic floating ring shaft seal was unsatisfactory due to excessive wear caused by inadequate centering force and failure of the sealing dam caused by erosion damage.

REFERENCES

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